PhD thesis

# Non-surgical intervention and assessment of anterior pelvic tilt in patients with symptomatic acetabular retroversion

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# 1. PREFACE AND DISCLOSURES

The original idea for this PhD originates from Professor, Søren Overgaard (co-supervisor), who observed patients in the orthopaedic hip outpatient clinic with symptomatic acetabular retroversion also appeared to have excessive anterior pelvic tilt. In this patient group, excessive anterior pelvic tilt is relevant as symptoms may be further exacerbated. Through discussions with radiologist, MD, Trine Torfing and Associate Professor Anders Holsgaard Larsen, it was proposed to investigate this potential relationship and develop and test a non-surgical intervention. Due to my qualifications as a physical therapist in the assessment of musculoskeletal dysfunction and exercise therapy, a collaboration was started, and a PhD protocol was compiled.

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## 1.1. Acknowledgments

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Thanks to all co-authors for providing their expertise in the manuscripts. Thanks to project-nurse Annie Gam-Pedersen for coordinating the intervention study, and to the orthopaedic surgeons who screened and recruited patients from the outpatient clinic. Thanks to Trine Torfing for teaching me how to analyze radiographic images, and Bo Mussmann for always helping when I had radiography questions. Thanks to René Bengtsen and the employees at the RIS/PACS office for providing me a workstation for analyzing the radiographic images. Thanks to the Biostatistical Consultancy Service at SDU. I would also like to thank all my colleagues, fellow students, research assistants, the staff in the Orthopaedic Research Unit, and the Department of Radiology at Odense University Hospital for their support and help.

Finally, a profound thanks to my family for their encouragement, support, and understanding.

**Anders Falk Brekke**

## 2. LIST OF PAPERS

The thesis is based on three studies (three papers). They will be referred to in the text by their Roman numerals, as indicated below.

| Study/paper | Authors, title, and status |
| --- | --- |
| I | Anders Falk Brekke, Søren Overgaard, Asbjørn Hróbjartsson, Anders Holsgaard-Larsen. **Non-surgical interventions for excessive anterior pelvic tilt in symptomatic and non-symptomatic adults: a systematic review**. [Published in EFORT Open Rev 2020;5:722-730] |
| II | Anders Falk Brekke, Anders Holsgaard-Larsen, Trine Torfing, Stig Sonne-Holm, Søren Overgaard**. Increased anterior pelvic tilt in patients with acetabular retroversion compared to the general population: A radiographic survey.** [Submitted to Acta Orthopaedica, August 27, 2020] |
| III | Anders Falk Brekke, Søren Overgaard, Bo Mussmann, Erik Poulsen, Anders Holsgaard-Larsen. **Exercise in patients with acetabular retroversion and excessive anterior pelvic tilt: A feasibility and intervention study**. [Submitted to Medicine & Science in Sports & Exercise, August 17, 2020] |

## 3. ABBREVIATIONS

The following abbreviations are used in text or legends in the thesis.

| | |
|---|---|
| AIA | Acetabular index angle |
| ANOVA | Analysis of variance |
| BMI | Body mass index |
| CERT | Consensus on Exercise Reporting Template |
| CI | Confidence interval |
| COS | Cross-over sign |
| EQ-5D-3D | European Quality of Life questionnaire (5 Dimensions, 3 Levels) |
| F | Female |
| FAIS | Femoroacetabular impingement syndrome |
| GRADE | Grades of Research, Assessment, Development and Evaluation |
| HAGOS | Copenhagen Hip and Groin Outcome Score |
| ICC | Intraclass correlation coefficient |
| IQR | Interquartile range |
| ISS | Ischial spine sign |
| ITT | Intention To Treat |
| LOA | Limits of agreement |
| M | Male |
| Mm | Millimeter |
| N | Numbers |
| *K* | Cohen's kappa coefficient |
| LCEA | Lateral center-edge angle |
| MCID | Minimal clinically important difference |
| NRS | Numeric ranking scale |
| OUH | Odense University Hospital |
| PAO | Periacetabular osteotomy |
| PI | Pelvic incidence |
| PP | Per protocol |
| PROMS | Patient-reported outcome measures |
| PTR | Pelvic-tilt-ratio |
| PWS | Posterior-wall sign |
| RCT | Randomized Controlled Trials |
| ROBINS-I | Risk Of Bias In Non-randomized Studies - of Interventions |
| SC-S | Sacrococcygeal joint–symphysis distance |
| SD | Standard deviation |
| STROBE | The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement |
| TIDieR | Template for intervention description and replication |

## 4. ENGLISH SUMMARY

**Background:** Acetabular retroversion is a variant of hip dysplasia characterized by a posterior maldirection of the cranial acetabular opening, which increases the risk of femoroacetabular impingement syndrome (FAIS). FAIS is associated with hip-related pain, and early development of osteoarthritis of the hip. FAIS may be further exacerbated by anterior pelvic tilt and some patients are treated with periacetabular osteotomy (PAO). There is currently no evidence for a non-surgical alternative for patients with this condition. Therefore, it is of interest to investigate the effect of non-surgical intervention, and further, to explore if patients with symptomatic acetabular retroversion and excessive anterior pelvic tilt might benefit from a home-based exercise program.

**Methods:** A systematic review was conducted, investigating the effect of non-surgical treatments in relation to symptoms, function, and pelvic tilt in adults. Furthermore, a radiographic case-control study was executed with the purpose of investigating whether pelvic tilt in patients with symptomatic acetabular retroversion was different from that in a general population. Finally, an intervention study was carried out to investigate feasibility and change in patient-reported symptoms of an 8-week home-based exercise program in patients with acetabular retroversion and excessive anterior pelvic tilt.

**Findings:** The systematic review was based on studies reporting heterogeneous study populations, interventions, and very low quality of evidence. In conclusion, no overall evidence for the effect of non-surgical treatment in reducing excessive anterior pelvic tilt and potentially related symptoms was found. In the radiographic case-control study, it was shown that the patient group had significantly larger anterior pelvic tilt, in comparison to the normal population. Furthermore, radiographic acetabular retroversion was highly prevalent in the general population. Finally, the 8-week exercise intervention was feasible with regards to dropout, adherence to exercise, and adverse events. Additionally, the ratio of patients using analgesics decreased significantly over the exercise period. However, no clinically relevant changes in self-reported hip-related pain, function, quality of life, nor anterior pelvic tilt were found.

**Conclusion**: The thesis demonstrated that patients with symptomatic acetabular retroversion have an increased degree of anterior pelvic tilt, which should be considered in the treatment, as pelvic tilt may further exacerbate symptoms. A prospective targeted exercise intervention on patients with acetabular retroversion and excessive anterior pelvic tilt did not lead to clinically relevant changes. Thus, the present study supports current literature, showing no evidence for the effect of non-surgical treatment in reducing excessive anterior pelvic tilt and potentially related symptoms in patients with symptomatic acetabular retroversion.

## 5. DANSK RESUMÉ (DANISH SUMMARY)

**Baggrund:** Acetabular retroversion er en variant af hofte dysplasi, der er kendetegnet ved en bagudrettet åbning af den øverste del af hofteledskålen, hvilket øger risikoen for afklemning imod lårbenet, og er forbundet med hofte-relaterede smerter og tidlig udvikling af artrose i hoften. Tilstanden kan blive yderligere forværret ved forøget fremadkipning af bækkenet, som er en frekvent observation hos indeværende patientgruppe. Nogle patienter har så svære symptomer, at de behandles operativt med en såkaldt periacetabular osteotomy. Der er i øjeblikket ikke evidens for et ikke-kirurgisk alternativ til patienter med denne tilstand. Derfor er det interessant at undersøge effekten af ikke-kirurgiske indgreb og yderligere at undersøge, om patienter med symptomatisk acetabular retroversion og forøget fremadkippet bækken kan drage fordel af et hjemmebaseret træningsprogram.

**Metoder:** Der blev foretaget et systematisk litteraturstudie for at undersøge evidensen for effekten af ikke-kirurgisk behandling i relation til symptomer, funktion og forøget fremadkippet bækken hos voksne. Endvidere blev et radiografisk case-kontrol studie gennemført, hvor det blev undersøgt om bækkenkipningen hos patienter med symptomatisk acetabular retroversion var forskellig sammenlignet med den almene befolkning. Endelig blev der udført et interventionsstudie for at undersøge gennemførbarheden og ændringen i patientrapporterede symptomer som følge af et 8-ugers hjemmebaseret træningsprogram hos patienter med acetabular retroversion og forøget fremadkippet bækken.

**Fund:** Det systematisk litteraturstudie var baseret på publikationer med heterogene studiepopulationer, interventioner og meget lav kvalitet af evidensen. Der blev ikke fundet nogen overordnet evidens for effekten af ikke-kirurgisk behandling til reduktion af forøget fremadkippet bækken og potentielt relaterede symptomer. I det radiografiske case-kontrol studium blev det vist, at patientgruppen havde signifikant højere grad af fremadkippet bækken sammenlignet med den almene befolkning. Endvidere fandt vi at en stor andel af den almene befolkning havde acetabular retroversion. Træningsintervention var gennemførbar i forhold til patienter som afslutter deres deltagelse i projektet, overholdelse af træningen og bivirkninger. Yderligere faldt ratioen af patienter som brugte smertestillende medicin signifikant. Imidlertid blev der ikke fundet nogen klinisk relevante ændringer i selvrapporteret hofte-relateret smerte, funktion, livskvalitet eller grad af fremadkippet bækken.

**Konklusion:** Studierne indikerer, at patienter med symptomatisk acetabular retroversion har forøget grad af fremadkippet bækken, hvilket bør medtages i overvejelserne af behandlingen, da fremadkippet bækken kan forøge hofte-relaterede symptomer. Træningsintervention førte ikke til klinisk relevante ændringer, hvilket således understøtter den aktuelle litteratur, der ikke viser nogen evidens for effekten af ikke-kirurgisk behandling til reduktion af forøget fremadkippet bækken og potentielt relaterede symptomer hos patienter med symptomatisk acetabular retroversion.

## 6. INTRODUCTION

### Motivation for the PhD

Prior to current PhD, it was observed in the outpatient clinic, that patients with acetabular retroversion also appeared to have a high prevalence of excessive anterior pelvic tilt. Acetabular retroversion is a potential cause of femoroacetabular impingement and a disabling condition of the hip, associated with pain, reduced level of function and quality of life, and early development of osteoarthritis. Anterior pelvic tilt causes downward displacement of the anterior acetabular rim, which may increase the likelihood of impingement, and thus potentially exacerbate symptoms. The preferred surgical procedure is a periacetabular osteotomy (PAO), which is a complex intervention with associated risk of complications and a long rehabilitation. PAO is indicated for young patients who experience persistent groin pain despite attempts at non-surgical treatment. Non-surgical treatment is supported with low to moderate level of evidence for a short-term effect in various types of femoroacetabular impingement. However, there is currently no evidence for non-surgical treatment in patients with acetabular retroversion and excessive anterior pelvic tilt, being candidates for a PAO. The overall aim of the thesis was to investigate a potential alternative to surgery for patients with symptomatic acetabular retroversion regarding symptoms, function, and pelvic tilt (**Study III**. Feasibility and intervention study). However, as the effect and certainty of the evidence of non-surgical treatments in improving symptoms and pelvic tilt in adults were unknown, we conducted a review of the literature to clarify this (**Study I.** Systematic review). Currently, there is no evidence if acetabular retroversion is associated with excessive anterior pelvic tilt, as indicated by clinical observations in the outpatient clinic. Thus, we investigated whether pelvic tilt in patients operated for acetabular retroversion was different from that in a general population (**Study II.** Radiographic case-control study).

### Etiology, prevalence and potential consequences of acetabular retroversion

Acetabular retroversion is a congenital variant of hip dysplasia,[98, 110] where the cranial opening of the acetabulum is posterior, compared to the normal anteverted orientation, which may be explained by externally rotated hemipelvises.[121] Acetabular retroversion is verified on an anteroposterior radiograph (in supine or standing position) by the cross-over sign (COS; the too-prominent cranial part of the anterior wall of the acetabulum is crossing the posterior acetabular wall) and the deficient posterior-wall sign (PWS; the posterior wall of the acetabulum is located medial to the center of the femoral head).[98] Due to the externally rotated hemipelvis, the ischial spine sign (ISS; the ischial spine is visible within the pelvic inlet) is also suggested as a radiographic sign of acetabular retroversion.[48] However, ISS does not affect the hip joint and thus does not contribute to symptoms in comparison to the presence of COS and PWS. The reported prevalence of acetabular retroversion is 4-7% in non-orthopaedic patients from anteroposterior radiographs in supine position, with pelvises exhibiting excessive anterior pelvic tilt excluded.[22, 132] This prevalence might be too high as the supine position tends to overestimate measures of acetabular retroversion due to increased anterior pelvic tilt.[43, 97] Moreover, this prevalence is based on trauma patients and not the general population with pelvises exhibiting excessive anterior pelvic tilt excluded. Thus, the prevalence of radiographic signs of acetabular retroversion from anteroposterior radiographs taken in standing position in the general population is unknown. The prevalence of acetabular retroversion is increased in patients with other hip development changes such as; developmental dysplasia of the hip, Legg-Calvé-Perthes disease,[22] and Slipped Capital Femoral Epiphysis.[5]

In acetabular retroversion, the prominent anterior acetabular wall causes acetabular over-coverage of the femoral head, which is a potential cause of femoroacetabular impingement. Femoroacetabular impingement was in the year 2016, defined as a syndrome (FAIS) by the international Warwick Agreement consensus statement.[31] This agreement is reflecting the relationship between the patient´s appropriate symptoms, clinical signs, and imaging findings. Femoral head over-coverage, as demonstrated in patients with acetabular retroversion is not uncommon in asymptomatic populations.[28, 78, 105, 131] Acetabular retroversion is a disabling condition associated with pain,[63] reduced level of function,[102] decreased health-related quality of life,[13] and development of osteoarthritis of the hip.[27, 30] It is estimated that approximately 25% of people in the general population will develop symptomatic hip osteoarthritis,[83] and 20% of those may be early hip osteoarthritis attributed by acetabular retroversion.[22, 27]

**Acetabular retroversion, anterior pelvic tilt, and femoroacetabular impingement syndrome**

FAIS is an overall term describing an early pathological contact between the acetabulum and the femoral neck, limiting hip range-of-motion in common activities of daily living.[122] Two types of impingement (pincer- and cam-type) are distinguished: The pincer-type is caused by an acetabular over-coverage as in acetabular retroversion, and the cam-type by a bulge on the femoral head-neck junction anterior, and the combination of the two types is frequently observed (**Figure 1**).[122]

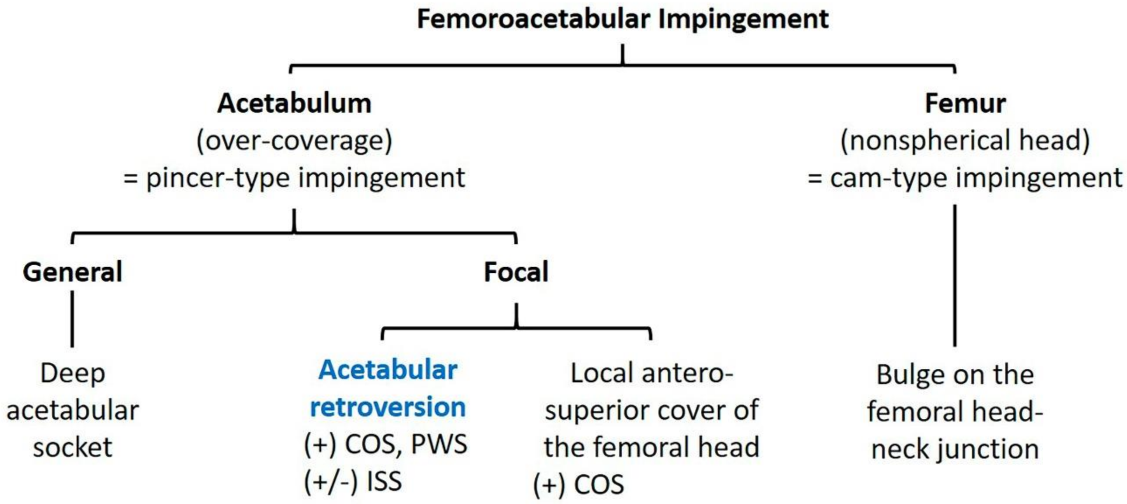



**Figure 1.** Classification of types of femoroacetabular impingement (with inspiration from Tannast et al,[122] Murphy et al,[84] and Jakobsen et al[45]).

Pincer-type FAIS (no reporting on isolated acetabular retroversion) is most often observed in young to middle-aged females (Females [3]:Males [1]).[122] Typical patients are 15 to 35 years of age,[45, 111] and physically active involving hip motion (i.e., sports or physically demanding occupation).[64, 98] Initially, symptoms are intermittent and often associated with activity, but gradually become more persistent.[98, 122] The presenting symptoms are mainly located to the groin area but can radiate to the buttock, thigh, and lower back. Clinical findings of acetabular retroversion are typically limited passive range-of-motion of the hip in flexion and internal rotation and a positive anterior impingement test (FADIR test) reproducing symptoms.[98] An initial anteroposterior radiograph of the pelvis in standing position is the standard imaging method for diagnosing acetabular retroversion.[46, 98, 122]

The risk of FAIS from femoroacetabular impingement caused by genuine acetabular retroversion may be enhanced by anterior pelvic tilt (i.e., functional acetabular retroversion)[100] as it causes downward displacement of the anterior acetabular rim. Anterior pelvic tilt functionally increases femoral head coverage,[98, 99] and consequently, increases the frequency of radiographic signs of retroversion.[14, 35, 98, 100] Currently, there is no evidence on association of acetabular retroversion with excessive anterior pelvic tilt and more importantly if patients undergoing PAO also demonstrate signs of excessive anterior pelvic tilt which, as described above, may further exacerbate symptoms.

**Treatment of patients with symptomatic acetabular retroversion**

There is no defined first-line treatment (i.e., the initial, preferred, or best treatment for a disease that combines the best efficacy with the best safety and/or the lowest cost)[16] in patients with FAIS.[31] However, it is suggested that the treatment algorithm for patients with FAIS should begin with non-surgical treatment[71] which may provide low-risk and low-cost treatment options to reduce the symptoms of FAIS.[52] However, non-surgical treatment, such as conservative care and physical therapy, is not supported by high-level evidence[51, 130] Conservative care is poorly described but could include patient education, activity and lifestyle modification, oral analgesia, intra-articular steroid injection, and watchful waiting.[130] Physical therapy includes both passive (e.g., soft tissue techniques, joint mobilization, and electrotherapy) and active exercise-based treatment. It is recommended that physiotherapist-led interventions should include exercise programs.[49] Presently, exercise-based[52] physiotherapist-led interventions[51] in patients with various types of FAIS are supported with a low to moderate level of evidence for a short-term effect.[75] However, an exercise program targeting to reduce FAIS by normalization of anterior pelvic may hypothetically be a preferred option in patients with acetabular retroversion and excessive anterior pelvic tilt as it reduces the downward displacement of the anterior acetabular rim. To our knowledge, no previous study has investigated an exercise intervention on a group of homogeneous patients with acetabular retroversion. Furthermore, our systematic review showed no evidence on non-surgical treatment in reducing symptoms, and excessive anterior pelvic tilt in adult exists.[23]

If non-surgical treatment is insufficient, surgery may be considered. Surgery aims to correct hip morphology to obtain free hip range-of-motion. The preferred surgical procedure in patients with acetabular retroversion is a PAO with a reorientation (anteversion) of the acetabular fragment or arthroscopically resection of anterior acetabular rim.[45, 137] A PAO is a technically demanding surgical procedure with risk of complications (i.e., injury to vessels or nerves, thrombosis, penetrating the joint cavity, delayed union of bone).[45] Neurovascular complications are the most frequently reported complications to occur in 0-5% of the cases.[45] Following surgery, a demanding rehabilitation period is required. Good long-term results (10 years) after PAO have been reported with a survival rate of 100% for not getting a total hip arthroplasty.[70, 116] However, due to this invasive surgery, it is relevant to investigate if non-surgical alternatives exist.

**Motivation for the studies**

Evidence is sparse on the effect of non-surgical treatment in reducing excessive anterior pelvic tilt and potentially related symptoms. It is not known if acetabular retroversion is associated with excessive anterior pelvic tilt, and the prevalence of radiographic acetabular retroversion in the general population. Furthermore, there is no evidence whether an exercise intervention targeting a reduction of anterior pelvic tilt can change patient-reported symptoms and the degree of anterior pelvic tilt in symptomatic patients with acetabular retroversion and excessive anterior pelvic tilt. Thus, the following study aims and hypotheses were investigated.

## 7. STUDY AIMS AND HYPOTHESES

The overall aim of the thesis was to investigate a potential alternative to surgery for patients with symptomatic acetabular retroversion regarding symptoms, function and pelvic tilt

### 7.1. Study I. Systematic review of the literature

The aim was to investigate the effect of non-surgical treatments in improving patient- and observer-reported outcomes related to symptoms, function, and pelvic tilt in symptomatic and non-symptomatic adults, and to assess the overall certainty of evidence.

### 7.2. Study II. Radiographic case-control study

The aim was to investigate whether patients with symptomatic and radiographically verified acetabular retroversion demonstrated increased anterior pelvic tilt, compared to a control group, and furthermore to evaluate the prevalence of acetabular retroversion in the general population.

### 7.3. Study III. Feasibility and intervention study

The aim was to investigate the feasibility of a progressive home-based exercise intervention targeting a normalization of excessive anterior pelvic tilt and the change in patient-reported symptoms in a prospective cohort of patients with acetabular retroversion and excessive anterior pelvic tilt.

It was hypothesized that an 8-week progressive home-based exercise intervention would be feasible with regards to adherence to exercise, exercise-related pain and adverse events, and would demonstrate clinically relevant improvements in patient-reported pain, function, and health-related quality of life, together with normalization of anterior pelvic tilt, in comparison with a prior control period.

# 8. METHODOLOGY

## 8.1. The methodological approach of the studies included in PhD thesis

Systematic review. Prior to designing the exercise intervention, a systematic review was conducted to investigate the evidence for the effect of non-surgical treatments in improving symptoms, function, and pelvic tilt in adults. A systematic literature review is a research methodology designed to answer a focused research question by systematically identifying, appraising, and synthesizing research evidence.[81] Systematic reviews are conducted in an unbiased, reproducible way to provide evidence for practice, policy-making, and identify gaps in research.[81] To ensure methodological transparency, a protocol outlining aim and methodology for the systematic review was registered online at PROSPERO (id: CRD42017056927, February 8, 2017) and has been updated January 1, 2018, and finalized June 16, 2020. The review was published in January 2020.[23] The systematic review protocol was developed in accordance with the PRISMA-P statement.[81] Level of evidence was 3, as the included low-quality studies lowered the level of evidence from what normally is considered for systematic reviews.

Radiographic case-control study. A radiographic case-control study was conducted to investigate whether increased anterior pelvic tilt in patients with acetabular retroversion, as clinically observed in the outpatient clinic, was different from that assessed in a general population. Frontal plane radiographs of patients from Odense University Hospital (OUH), prior to treatment with PAO, were compared to those of controls. A case-control study is an observational research method by which questions regarding condition-specific characteristics and prevalence can be investigated.[76] No a priori protocol was registered outlining aim and methodology. To ensure sufficient reporting of the study, the STROBE[128] reporting guideline for case-control studies was used. The current case-control study was level 3 evidence in the category "How common is the problem?".[39] For increasing the level of evidence, a systematic review including comparable studies must be conducted. However, conducting a systematic review for answering the research question was not an option, as this case-control study was the first comparing the degree of pelvic tilt in a homogeneous study group of patients with acetabular retroversion with the general population. Furthermore, the current case-control study was the first to report the prevalence of radiographic signs of acetabular retroversion in the general population.

Intervention study. A high-quality randomized controlled trial (RCT) (level of evidence 2) provides the most reliable evidence on the efficacy of healthcare interventions.[80] However, as the literature on the current topic is sparse, there was not clinical equipoise for conducting an RCT, comparing an exercise intervention targeting a reduction of excessive anterior pelvic with PAO, for the treatment of hip-related symptoms in patients with acetabular retroversion. Clinical equipoise means that there is genuine uncertainty in the expert medical community over whether a treatment will be beneficial.[25] In our case, there is evidence supporting a reduction in symptoms following PAO due to a reduction/elimination of acetabular over-coverage.[109] Contrary, there is no evidence supporting that an exercise intervention targeting a reduction of excessive anterior pelvic tilt is able to reduce acetabular over-coverage functionally,[23] and as a result, improve hip-related symptoms. Thus, a quasi-experimental design was chosen. In the repeated measures design (i.e., within-subjects design/prospective cohort study – level of evidence 3), one group of patients is tested repeatedly over time and acts as their own control. The advantges of this design include a higher sample size in conditions where there are few participants (there are about 50 patients per year at OUH), which increases the power and thus lowers the probability of a Type 2 error.[95] Further, participant characteristics variability (body weight, anthropometry etc.) is low over the intervention period, and thus a difference between the measurements is more likely to reflect true change.[95] A disadvantage of the repeated measures design is that the condition (level of hip-related symptoms and pelvic tilt) is not necessarily constant over time independently of intervention. Therefore, to test for whether symptoms and pelvic tilt changed over time, independent of the exercise program, there was a prior control period, with the same duration as the training period. It is recommended that exercise based treatment in young to middle-aged active patients with hip-related pain should have a duration of at least 12 weeks.[52] However, we found that a control period of 12 weeks without any intervention was too long and thus not ethical. Therefore, it was decided that an 8-week control period was followed by an 8-week exercise period, and subsequently, the patients were encouraged to continue with the exercise program for an additional 16 weeks. Thus, the total duration of the intervention would exceed 12 weeks as recommended. A preparatory pilot study tested a preliminary progressive 8-week exercise program targeting a reduction of excessive anterior pelvic tilt in three young female patients with symptomatic acetabular retroversion. The pilot study included mandatory face-to-face sessions every second week in connection with the progression of the exercise program. Such a session included practical demonstration of new exercises, rehearsal of previously instructed exercises if needed, guidance in progression and/or personalization of the exercise program, and advices in activity modification. Besides improvements to the exercise program, it was demonstrated that the preferred training was home-based due to difficulties in meeting for supervised sessions. The participants in the pilot study found it easy to exercise according to the printed program and instructions provided, and therefore sufficient to have the opportunity to contact the study investigator – Anders Falk Brekke – (AFB) if needed instead of scheduled mandatory meetings/booster sessions. Additionally, patients with acetabular retroversion are referred from a large geographic area, and as a result, a pragmatic approach of a home-based intervention was chosen. Consequently, due to the novelty of the home-based exercise program investigating change of a not previously tested intervention, we also decided to assess the feasibility together with change in patient-reported symptoms, and pelvic tilt. To ensure methodological transparency, a protocol and statistical analysis plan was registered online at ClinicalTrials.org (id: NCT03578562, July 3, 2018) and has been updated on November 9, 2018, December 10, 2019, and December 20, 2019. The feasibility part of the study was not initially registered, but this deviation was accounted for in the published statistical analysis plan. Due to the non-randomized design, the STROBE[128] reporting guideline for cohort studies was used along with the TIDieR[38] and CERT[113] checklist for reporting interventions and exercise programs, respectively.

The methodology of the three studies is described separately in the following section due to their diversity.

## 8.2. Study I. Systematic review of the literature

### Level of evidence 3

<u>*Eligibility criteria*</u>

Studies were eligible if they were non-surgical interventions aimied at reducing symptoms and/or anterior pelvic tilt in symptomatic or non-symptomatic adults (>18 years old) with excessive anterior pelvic tilt. Studies were excluded in cases with populations restricted to specific diseases or severe conditions (e.g., neurological diseases, diseases affecting the posture, degenerative conditions, intervertebral discus herniation, and osteosynthesis of the lumbopelvic region). Studies on pregnancy were excluded due to the natural change of spinopelvic posture. There were no language or publication date restrictions.

<u>*Information sources and selection of studies*</u>

The following databases were selected in consultation with an experienced research librarian to locate the relevant available published bio-medical research. In the databases: MEDLINE, EMBASE, Web of Science, and Cochrane Central Register for Controlled Trials (CENTRAL), a systematic search was performed by AFB, including studies prior to February 2017. Due to a long submission process, an additional search for new studies was conducted in March 2019. No additional studies were included. The search strategy was prepared in collaboration with the research librarian. The search strategy was intentionally very sensitive, (i.e., resulting in many hits), to ensure that relevant citations were not missed.[10] Hence, two search strings consisting of only two topics, separated by the Boolean operator AND were developed: one targeting pelvic tilt, and the other targeting posture. AFB screened titles and abstracts for potentially eligible studies. AFB and co-author Anders Holsgaard-Larsen (AHL) independently assessed full-text articles for inclusion. Disagreement was resolved by consensus.

<u>*Data collection process*</u>

A standard form was developed for data item extraction on; year of publication, study design, participant characteristics, intervention type, outcomes, results, and adverse effects. The primary outcome was *Patient-Reported Outcomes* (symptoms, function, and quality of life), and *Observer Reported Outcomes* (measurements of pelvic tilt) were secondary.

*Risk of bias assessment*

The risk of bias for each study was assessed independently and then discussed by AFB and AHL. In case of disagreement, a third co-author (Asbjørn Hróbjartsson, formerly affiliated with the Nordic Cochrane Center in Copenhagen) was consulted. The Cochrane network is recognized as representing a high-quality international standard in systematic reviews and meta-analysis. Therefore, risk of bias assessment tools from Cochrane were chosen.

Randomized Controlled Trials (RCT) were assessed using *Cochrane Collaboration's tool for assessing risk of bias in Randomized Controlled Trials.*[37] Bias was assessed as a judgment (low, unclear, or high) for individual elements from five domains (Selection, Performance, Attrition, Reporting, Detection, and Other sources of bias). The domain *Other sources of bias* is covering any important concerns about bias not addressed within the other bias domains. Finally, the overall risk of bias across the RCT´s was assessed (low, unclear, or high).

Non-randomized studies were assessed using *ROBINS-I tool* (*Risk Of Bias In Non-randomized Studies - of Interventions*).[117] The ROBINS-I tool is based on the Cochrane Risk of Bias tool for randomized trials, and therefore, provides a systematic way to organize and present the available evidence relating to the risk of bias in non-randomized studies of interventions. The types of studies that can be evaluated using this tool are quantitative studies estimating the harm or benefit of an intervention, which did not use randomization to allocate units to comparison groups. These include; cohort studies, case-control studies, controlled before-and-after studies, interrupted-time-series studies, and controlled trials in which intervention groups are allocated using a method that falls short of full randomization (quasi-randomized studies). Bias was assessed as a judgment (low, moderate, serious, critical, or no information) for individual elements from seven domains (Confounding, Participant selection, Intervention classification, Departure from intended interventions, Missing data, Measurement of outcomes, and Selection of reported results). The risk of bias across the seven domains was assessed as (low, moderate, serious, critical, or no information). Finally, the overall risk of bias across the non-randomized intervention studies was assessed (low, unclear, or high).

*Synthesis of results*

Data were synthesized qualitatively due to expected and encountered variation of study designs and heterogeneity in results. The overall certainty of the evidence was assessed with inspiration from The *Grades of Research, Assessment, Development and Evaluation (GRADE)* approach.[3] GRADE is a transparent and internationally recognized approach to grading quality (certainty) of evidence and strength of recommendations (high, moderate, low, or very low). Domains for downgrading the quality of evidence are; Risk of bias, Inconsistency of results, Indirectness of evidence, Impression, and Publication bias.

### 8.3. Study II. Radiographic case-control study
### Level of evidence 3

*Ethics and approvals*

The study was approved by the Danish Patient Safety Authority (3-3013-1660/1), and the executive board of the Copenhagen City Heart Study (HEH-2015-045) for the study group and control group, respectively.

*Setting and participants*

Inclusion criteria for the study group. We identified and included patients with symptomatic acetabular retroversion  between the age of 20 and 40 years prior to PAO at OUH. The age range for inclusion was defined so that it was comparable with the patients in study III (inclusion criteria; 18 to 40 years old). However, the low end of the age range (20 years) was adjusted as the youngest available age range in the control group was 20-25 years. Included patients should have undergone preoperative anteroposterior pelvic radiographs in standing position showing radiological signs of retroversion (COS+PWS), which were verified using computed tomography scanning (CT-scan), and had the PAO performed between January 2007 (the year of the first PAO at OUH) and January 2018. Patients should have had symptoms for more than 3 months, non-surgical treatment was not deemed successful in reducing pain, and were diagnosed with symptoms of FAIS during physical examination.[98]

We excluded patients with radiographic sign of hip osteoarthritis (<2 mm joint space), previous lumbar, pelvic or hip related surgery, childhood hip pathology (slipped capital femoral epiphysis, Perthes disease), Tönnis foramen obturator index (FOI)[126] (maximum horizontal width of the right obturator foramen divided by the left) exceeding the limit values of 0.7–1.8 in pelvic rotation[44] making the assessment of COS and PWS unreliable,[119] and poor image quality making it impossible to assess pelvic tilt.

Inclusion criteria for the control group. Controls were randomly selected from the general population among 4,151 participants from the longitudinal health survey *The Copenhagen City Heart Study III* (CCHS-III)[44, 106] recorded from 1991 to 1994. During that survey, pelvic radiographs, among others, were taken to assess osteoarthritis in the general population.
Parameters for matching were; age due to the association with a flattening of the lumbar lordosis[6] (i.e., potentially reducing anterior pelvic tilt), and sex due to the gender-wise differences on pelvic morphology.[108] The participants in CCHS-III were generally older compared to our study group. Therefore, it was only possible to match 1 patient with a maximum of 2 controls. Matching 2 (controls):1 (patient), was performed by an independent employee, on 5-year age intervals (20–25; 26–30; 31–35; 36–40 years), and sex. Anteroposterior pelvic radiographs in standing position of the controls were assessed. Exclusion criteria were the same as for cases. In case of exclusion, a matched replacement was randomly found.

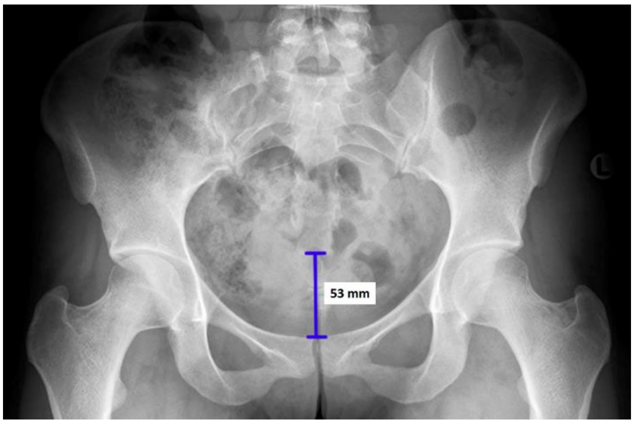
*<u>Radiographic procedure</u>*

In both groups, anteroposterior radiographs were recorded in standing position, with the arms crossed in front of the chest, and the X-ray beam centered approximately two fingerbreadths over the symphysis in the vertical midline. Patients stood with 15 degrees of bilateral internal rotation of the hips, and the controls with the feet pointing straight forward. The tube-to-film distance was 115 cm and 120 cm for patients and controls, respectively. We do not believe that this difference caused any bias. Radiographs were assessed digitally using TraumaCad® software for the study group, and conventionally on printed film using a protractor and ruler, for the control group. Digital and analogue radiographs have been shown to be comparable.[17] However, a shorter tube-to-film distance increases magnification, [61] (i.e., study group pelvises are magnified on the radiograph). Nevertheless, the current difference in the tube-to-film distance of 5 cm will not significantly influence metric measurements as the X-ray beam comes from multiple points. Thus, the radiation is not only conical on the anatomy in focus but also slightly scattered, which reduces the magnification effect.[61] Measurements of angles are not affected by the magnification effect.

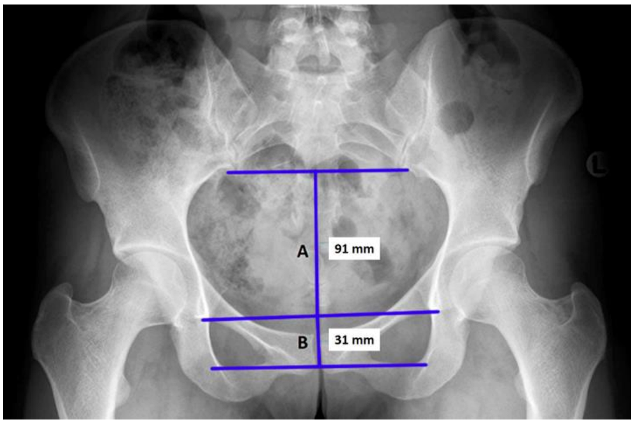
<u>*Outcome measures*</u>

Pelvic tilt. True pelvic tilt is defined as an angle measured in the sagittal plane.[120] In contrast to anteroposterior radiographs, which is the standard imaging method for diagnosing acetabular retroversion, lateral radiographs of the pelvis are not routinely conducted due to radiation dose and are thus not available for tilt assessment. Thus, different surrogate measures for pelvic tilt, measured on anteroposterior radiographs, have been proposed and are relevant for the current study because only anteroposterior radiographs, regarding both patients and controls, were available. The *sacrococcygeal joint–symphysis distance*[120] (**Figure 2A**) is reported having the strongest positive correlation to true pelvic tilt of six different parameters for both sexes ($r \approx 0.6$, p <0.001) (the angle measured between a horizontal line and a line connecting the upper border of the symphysis with the promontory).[120] However, measuring the *sacrococcygeal joint–symphysis distance* may be difficult due to overlying bowel obscuring more posterior structures. Thus, we also used a second method suggested by Schwarz et al,[107] who proposed that the *pelvic-tilt-ratio* (**Figure 2B**) obtained from anteroposterior radiographs might be more precise for assessing pelvic tilt than a single distance measure such as the *sacrococcygeal joint–symphysis distance. Pelvic-tilt-ratio* is considered a valid estimate of true sagittal pelvic tilt[107] and was accordingly a relevant surrogate measure for pelvic tilt together with the *sacrococcygeal joint–symphysis distance*.

Acetabular retroversion. Acetabular retroversion was defined as the combined radiographic presence of COS and PWS (COS+PWS) (**Figure 2C**).[98] COS+PWS are indicative of genuine acetabular retroversion. The ischial spine sign (ISS) is also related to acetabular retroversion and suggested as a radiographic sign of an externally rotated hemipelvis (**Figure 2C**).[48] The ischial spine, however, is not an anatomically part of the hip joint and thus not related to FAIS.[48] Furthermore, the ISS is not changed by a PAO as opposed to the COS and PWS. Additional radiographic signs potentially related to acetabular retroversion were assessed: lateral center-edge angle (LCEA, >40° is indicative of acetabular retroversion)[46] (**Figure 2E**) and acetabular index angle (AIA, <0° is indicative of acetabular retroversion) (**Figure 2F**).[46] The COS-ratio was calculated as the ratio of the length of the anterior acetabular wall lying anterior to the posterior acetabular wall in the cranial portion of the joint to the entire length of the acetabulum (**Figure 2D**).[87] The COS-ratio was assessed for the patient group only, as previous drawings on the screen-film radiographs made accurate measure impossible.




A

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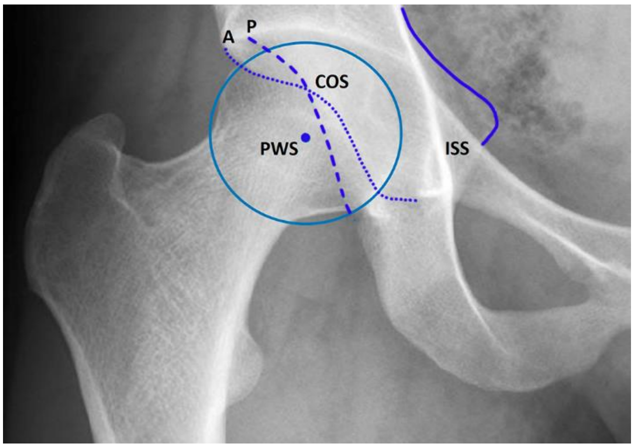


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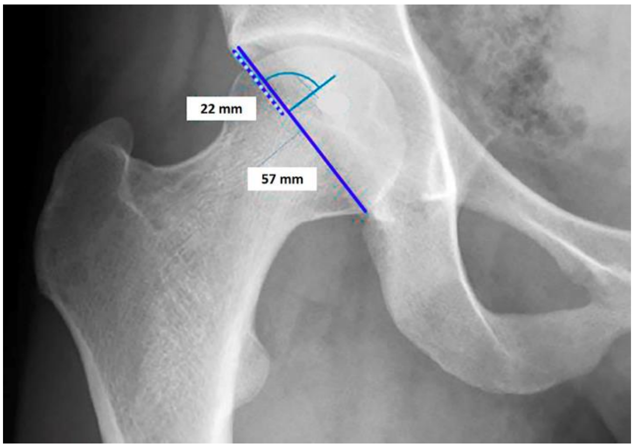


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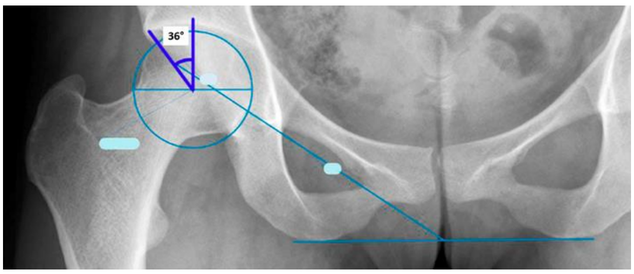


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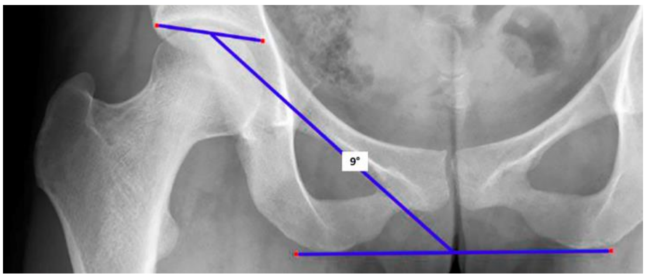


F

**Figure 2**. Sections of an anteroposterior pelvic radiographs in standing position (A – F)

**A**, Pelvic tilt assessed by measuring the distance from the sacrococcygeal joint to the upper edge of the symphysis (53 mm on the figure). Increased anterior pelvic tilt results in a greater *sacrococcygeal joint–symphysis distance*.

**B**, Pelvic tilt assessed by *pelvic-tilt-ratio*. Three transversal lines are drawn; 1) between the inferior margins of the sacroiliac joints, and 2) between the superior and 3) inferior borders of the obturator foramina. The *pelvic-tilt-ratio* is the ratio (B/A) between the central height of the obturator foramina and the height of the lesser pelvis (*pelvic-tilt-ratio* = (31 mm/91 mm) = 0.34 on the figure). Neutral, anterior, and posterior pelvic tilt is indicated by *pelvic-tilt-ratio* = 0.5, *pelvic-tilt-ratio* <0.5, and *pelvic-tilt-ratio* >0.5, respectively.

**C**, The cross-over sign (COS) appears when the cranial part of the anterior wall of the acetabulum (dotted line A) is crossing the posterior acetabular wall (banded line P). The posterior wall sign (PWS) is present when the posterior wall of the acetabulum is located medial to the center of the femoral head (blue dot). The ischial spine sign (ISS) is present when the ischial spine is visible within the pelvic inlet (all three signs for acetabular retroversion is positive on the figure).[17]

**D**, The cross-over sign ratio (COS-ratio) is measured as the ratio of the length of the anterior acetabular wall lying anterior to the posterior acetabular wall in the superior portion of the joint (dotted line, 22 mm) to the entire length of the acetabulum (solid line, 57 mm). (The COS-ratio is 0.39 on the figure). COS-ratios >33% to 50% indicate relatively severe retroversion.[87]

**E**, The lateral center-edge angle of Wiberg (LCEA) is measured between two lines drawn from the center of the femoral head, one running vertically perpendicular to a line connecting the inferior ischial tuberosities, and the other to the edge of lateral acetabular sourcil. (LCEA is 36° on the figure). Acetabular over-coverage is characterized by an LCEA >40°.[46]

**F**, The acetabular index angle of Tönnis (AIA) is measured between a line connecting the inferior ischial tuberosities and a line connecting the lateral and medial edges of the acetabular sourcil. (AIA is 9° on the figure). Acetabular over-coverage is characterized by an AIA <0°.[46]

Data quality assessment

All outcome measures were evaluated by AFB and assessed bilaterally in both groups, regardless of unilateral or bilateral symptoms. Prior to assessments, interrater reliability analysis was performed on 50 randomly selected digital radiographs (50 pelvises / 100 hips) by an experienced radiologist (Trine Torfing) and AFB.

Cohen's kappa coefficient (*k*) was calculated for the categorical outcome measures (COS = 0.64, PWS = 0.89, ISS = 0.91). The kappa coefficient indicates the agreement between the two raters beyond that what is expected by chance.[112] Following standards have been proposed for the strength of agreement: ≤0 = poor, 0.1–0.2 = slight, 0.21–0.40 = fair, 0.41–0.60 = moderate, 0.61–0.80 = substantial, and 0.81–1 = almost perfect.[62] An interrater reliability coefficient of only *k* = 0.64 in the assessment of COS, may indicate potential measurement bias. The disagreement in observations was random between the two raters, and thus measurement bias in the final assessments are unlikely. However, this lead to further improvements in using the TraumaCad® software (contrast, magnification, and invert colors) after which there was agreement between the two raters, on images where there previously had been disagreement.

Intraclass correlation coefficient (two-way random effects model for absolute agreement)[59] ($ICC_{2.1}$) was calculated for the continuous outcome measures (*sacrococcygeal joint–symphysis distance* = 0.97, *pelvic-tilt-ratio* = 0.92, LCEA = 0.91, AIA = 0.96, COS-ratio = 0.95). ICC reflects both the degree of correlation (correlation coefficient *r*) and agreement between the measurements. Compared to correlation, ICC is based on analysis of variance instead of paired observations. Hence, data may correlate perfectly (*r* = 1) without being reliable. Following standards have been proposed for ICC reliability: ≤0.5 = poor, 0.5–0.75 = moderate, 0.75–0.9 = good, and >0.9 = excellent.[59] The model reflects the two-way random effects ANOVA, in which both the participants being assessed (sample) and the raters are considered randomly chosen from their respective background populations.

Bland-Altman plots (**Figure 3, A and B**) with associated 95% of limits of agreement (LOA) (mean difference ±1.96 SD) were used to assess interrater agreement and potential bias for the two methods to measure pelvic tilt. The *sacrococcygeal joint–symphysis distance* measurements had an interrater mean difference of -1.3 mm (LOA: -13.9 mm to 11.2 mm), which is small and clinically acceptable. No systematic bias was observed in either interrater difference or to the magnitude of the measurements. In Figure 3-A, it is visualized that there is disagreement in 7 of the observations as they are placed close to or outside the LOA. Subsequent evaluation revealed that in case of poor quality images, the typical cause of disagreement was that the horizontal line between the fourth and fifth sacral vertebrae, or an inter-coccygeal joint was selected instead of the sacrococcygeal joint. Thus, a LOA of approximately 25 mm in measuring the *sacrococcygeal joint–symphysis distance* does not reflect a threshold of error expected in the measurement, but rather random error of choosing a false joint line. Therefore, precaution should be taken in clinical assessment of *sacrococcygeal joint–symphysis distance* in poor quality images. On the contrary, measurement error is small in good quality images.

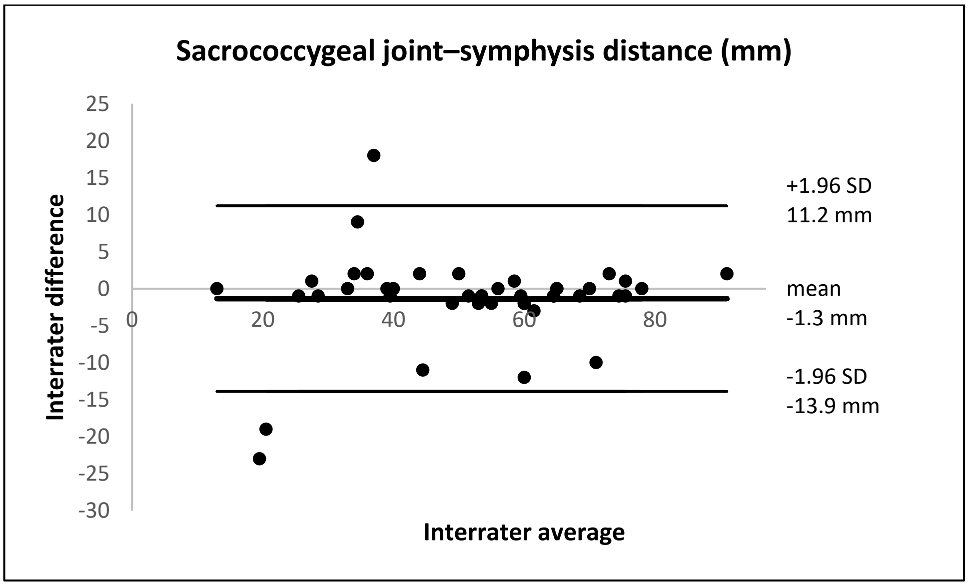


**Figure 3-A**. Bland Altman plot of the interrater agreement assessment on the *sacrococcygeal joint–symphysis distance* measurements.

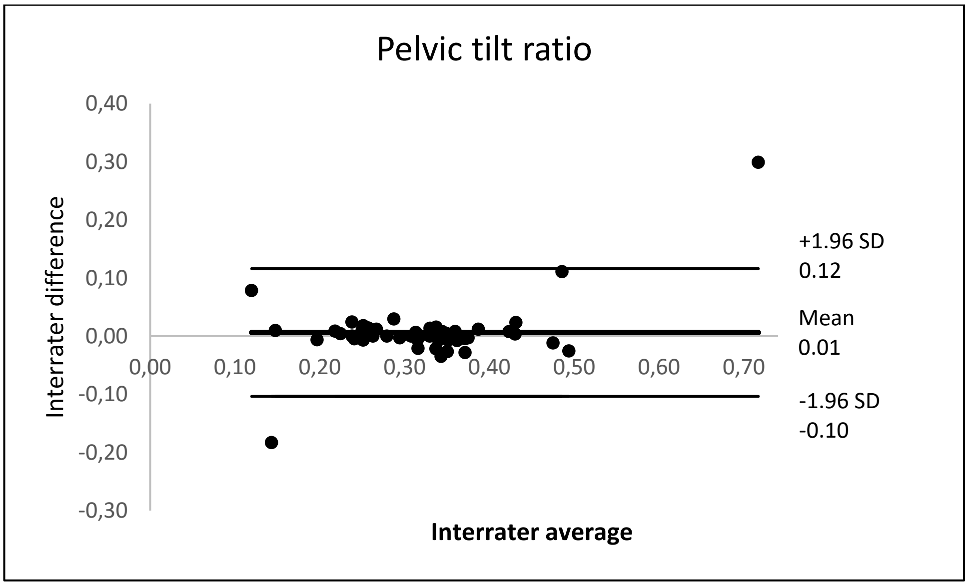


**Figure 3-B**. Bland Altman plot of the interrater agreement assessment on the *pelvic-tilt-ratio* measurements.

The *pelvic-tilt-ratio* measurements had an interrater mean difference of 0.01 (LOA: -0.10 mm to 0.12), which is small and clinically acceptable. No systematic bias was observed in either interrater difference or to the magnitude of the measurements. In Figure 3-B, it is visualized that there is disagreement in 4 observations as they are placed close to or outside the LOA. Subsequent evaluation revealed that disagreements were due to incorrect readings or typing errors. After correcting disagreements by new independent measurements, the new calculated values were: ICC = 0.99. Thus, LOA of approximately 0.2 in measuring the *pelvic-tilt-ratio* does not reflect a threshold of error expected in the measurement, but rather random error due to reading or typing error. Landmarks that were used clinically for the *pelvic-tilt-ratio* measurements were easily visualized on all radiographs.

Although all patients were diagnosed with acetabular retroversion (COS+PWS) by either radiographs and/or verified by CT-scans, the image quality was assessed in all the included radiographs to ensure complete data for equal comparison between the groups.

<u>Statistics</u>

The study sample size was pragmatically decided as all eligible patients who had a PAO performed from January 2007 (the year of the first PAO at OUH) to the end of data collection. Each included patient was intended to be matched with two controls. The sample size for the interrater reliability assessment was 50. It was pragmatically chosen as it was a value between two calculations with different 95% CI widths = 0.15 (sample size n = 26) and 0.10 (sample size n = 56). In both calculations there were an expected ICC = 0.90, alpha = 0.05, and power = 0.80. A power of 100% was subsequently calculated for both the *sacrococcygeal joint–symphysis distance* and *pelvic-tilt-ratio* using the above ICC values.

The distribution of data was investigated using visual inspection of histograms and Quantile-Quantile (QQ) plots, and the Shapiro-Wilk test. Non-parametric statistics were used accordingly. Participant characteristics were reported in medians with interquartile ranges (IQR). Potential between-group differences were tested using the two-sample Wilcoxon rank-sum test and the Chi-square test on continuous and dichotomous data respectively.

A nonparametric regression model, adjusted for age, BMI, and sex, was used to test potential between-group differences in median pelvic tilt supplied with 95% confidence intervals (95% CI). Age and BMI are potentially related to pelvic tilt, [6] and the *sacrococcygeal joint–symphysis distance* is reported greater in females compared to males at the same degree of pelvic inclination.[108]

A p-value ≤0.05 was considered significant. STATA/IC 16 (StataCorp. LP, College Station, TX, USA) was used for the statistical analysis.

### 8.4. Study III. Feasibility and intervention study

**Level of evidence 3**

Study design

In a paired single-center, prospective home-based intervention study, patients were used as their own controls. Following baseline examinations, an 8-week control period was followed by an 8-week exercise period. Subsequently, the patients were encouraged to continue their exercise program for an additional 16 weeks.

Participants

Eligible patients with retroversion and referred to the outpatient clinic for PAO at Odense University Hospital (Denmark) but with symptoms not adequate for surgery were recruited from November 2018 to December 2019. Inclusion criteria were: age 18 to 40 years old(legal age), having less risk of signs of degenerative changes to the hip joint, and presence of acetabular retroversion (COS+ PWS)[98] ascertained from a frontal pelvic radiograph in a standard standing position. Exclusion criteria were: pelvic-tilt-ratio greater than 0.5 indicating posterior pelvic tilt;[107] radiographic sign of hip osteoarthritis (<2 mm joint space); previous lumbar, pelvic or hip-related surgery; conditions not allowing exercise therapy; a body mass index (BMI) above 35; or not understanding spoken and/or written Danish language.

Procedures

All patients received individual face-to-face information and practical instructions for the exercise intervention, together with a printed exercise program and training diary (paper III – Appendix A) at Odense University Hospital after the 8-week control period. The session typically had a duration of 1 to 1½ hour. The patients were encouraged to bring a companion to, e.g., take notes, record video of the exercises and instructions for correction of excessive anterior pelvic tilt. For the full description of the rationale for the exercise program, see paper III – Appendix B. In brief, the home-based exercise program was inspired by the international Warwick consensus statement on FAIS,[31] previous exercise studies regarding various types of FAIS patients,[19, 40, 114, 133] and functional anatomy.[72] The intervention consisted of (i) education in the hip condition and activity modification, and (ii) physical exercises. (i, instructions) The patients were encouraged: Not to begin new physically strenuous activities as it may cause extra stress to the hip; Not to place the symptomatic hip(s) in a maximum flexed position as it increases the risk of impingement; Not to sit with the legs crossed as it increases the risk of impingement; Avoid excessive anterior pelvic tilt in the normal daily living and correct it by posteriorly tilting the pelvis when needed. (ii, exercises) Because excessive anterior pelvic tilt is related to a body posture with increased lumbar lordosis[101] and flexion of the hip joint,[100] exercises were chosen to normalize range-of-motion by stretching for posterior pelvic tilt mobility (anterior hip, low back, anterior thigh). The purpose of the muscle strengthening exercises were to increase capability in maintaining a position of normal anterior pelvic tilt, i.e., strengthening hip extensor muscles and abdominal muscles for tilting the pelvis posteriorly. Furthermore, proprioceptive exercises focusing on improving general body core stability and lumbar/pelvic movement control were introduced. In addition, hip abduction- and external rotation strengthening exercises for avoiding impingement in the adduction/internal position were a part of the complete exercise program. The intervention was in line with a consensus recommendation on the content of exercise-based treatment for people with hip-related pain,[52] which is supported with moderate evidence. The program (30–45 min) should be completed three times a week, with an optional extra session, allowing a rest day between each session. The progression (intensity, number of repetitions and/or level of difficulty of the exercises) increased every second week. However, some personalization of the exercise program (e.g., doing fewer repetitions or omitting an exercise that caused pain) was permitted and was to be noted in the training diary.

*Stopping guidance*

There was no *a priori* stopping guidance. However, patients were instructed to contact AFB in case of questions regarding the exercise program or experience of exercise-related discomfort/pain. If patients experienced exercise-related pain above 4 on a 0–10 numeric ranking scale (NRS),[123] where 0 is “no pain” and 10 is “pain as bad as it could be,” a booster session was added. A booster session consisted of an individual face-to-face consultation with AFB at the hospital, where practical instruction in the execution of exercises and/or advice of personalization to the exercise program was given. Ultimately, if pain could not be reduced below 4 on the NRS, the training was stopped and the referring physician contacted.

<u>Outcome measures</u>

*Feasibility*

In preparation for a clinical study, a feasibility study askes ´whether something can be done, should we proceed with it, and if so, how.´[18] The current feasibility investigation concerned the execution of the exercise program (intervention delivery) to identify, understand and correct potential problems and thus optimize the intervention.[57] We prospectively defined good feasibility[4] of the exercise intervention as; (i) a dropout rate ≤10%, (ii) adherence to the exercise program of ≥75% completion (18 out of 24 sessions), (iii) the ratio of training sessions increasing pre- to post exercise-related pain (NRS >4) should not increase, (iv) no serious exercise-related adverse events, and (v) no increase in usage of hip-related analgesics. Parameters regarding feasibility were recorded in the self-reported training diary.

*Time-points*

The intervention consisted of three parts: a control period, an exercise period, and an optional additional exercise period. The three periods were defined by four time-points were outcome measures were collected: T1) baseline, T2) start-up of exercise intervention, 8 weeks from baseline, T3) end of exercise intervention after 8 weeks (primary endpoint), and T4) follow-up after 16-weeks (paper III – see Appendix C) (**Figure 4**).

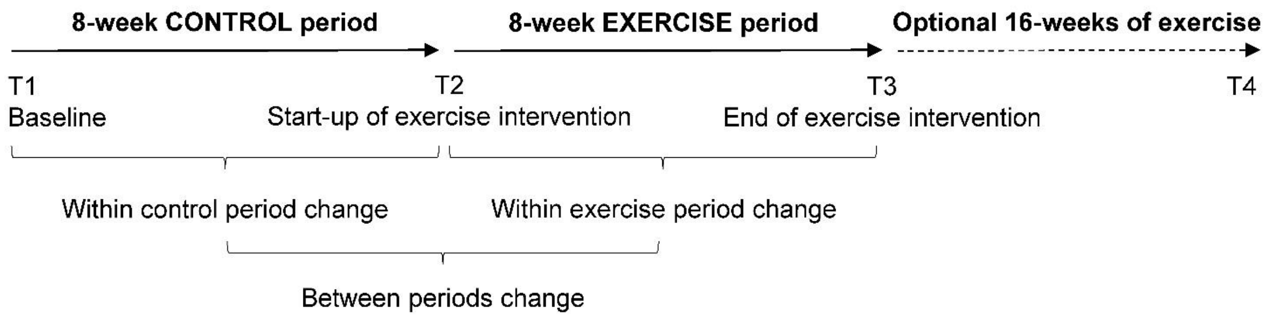


**Figure 4.** Study design and time-points

Primary outcome measure

The between-period change score in the pain subscale of the Copenhagen Hip and Groin Outcome Score HAGOS questionnaire[124] (HAGOS-PAIN) at T3 was registered *a priori* as the primary outcome measure. HAGOS is a condition-specific questionnaire, which has been developed for young and physically active patients with hip and/or groin problems. HAGOS ranges from 0 to 100 (0 equals "extreme hip and/or groin problems" and 100 equals "no hip and/or groin problems") and consists of six subscales: Pain, Symptoms, Physical function in daily living, Physical function in Sport and Recreation, Participation in Physical Activities, and hip and/or groin-related Quality of Life. The past week is taken into consideration when answering the questions.[124] HAGOS has shown good reliability, validity, and responsiveness in young to middle-aged patients with longstanding hip and/or groin pain,[124, 125] and has been evaluated amongst the most appropriate patient-reported outcome measures (PROMS) for use in young and middle-aged active adults with hip-related pain.[42] The patients were asked to focus the questions on the most symptomatic hip in case of bilateral symptoms. All questionnaires were printed on paper and collected by either staff from the radiology department, in connection with the EOS scan, or handed in personally to AFB.

Secondary outcome measures

*Patient-reported outcome measures*

Secondary outcome measures included between-period change scores of the remaining five HAGOS subscales[124], and the European Quality of Life questionnaire (EQ-5Dimensions-3Levels)[115] – index value set for Denmark – ranging from 0 to 1 (0 equals death and 1 equals full health). The EQ-5D-3L is considered a suitable generic questionnaire for use in addition to HAGOS.[42] The clinimetric properties for EQ-5D-3L in patients having FAIS have not been specifically reported, but EQ-5D-3L has been validated as a generic measure of general health.[21]

*Objective outcome measure*

Change in pelvic tilt (sagittal inclination in degrees) was measured with EOS scanning (EOS Imaging, Paris, France) as the angle between a horizontal line and a line connecting the upper border of the symphysis with the sacral promontory (paper III – Appendix D).[120]

EOS is a low-radiation X-ray scanner capturing the selected body part of a person in standing position and is an emerging alternative to plain radiographs. Pelvic EOS scans provide diagnostic qualities similar to plain radiographs using 44% less radiation when assessing signs of acetabular retroversion[85] and since the pelvic region is sensitive to radiation, especially in children and adolescents EOS is a preferred technology for low doses of radiation. Additionally, EOS has shown excellent reliability in measuring the sagittal alignment of the pelvis,[55] and has been found reliable[82, 85] and valid[65] in assessing pelvic configurations and acetabular morphology.[8] The EOS image is generated by two perpendicular fan-shaped X-ray beams creating a slot-scanning made line-by-line by a collimated beam and detector that moves vertically.[41] Thus, the EOS imagine system allows for simultaneous frontal and sagittal weight bearing radiographs providing : (i) anteroposterior radiograph in standing position, which is the standard imaging method for diagnosing acetabular retroversion, (ii) simultaneous sagittal radiograph, which is the reference standard plane for evaluating pelvic tilt.

EOS was recorded in a standard weight bearing standing position, with the hands on a handle 180 cm above the ground, and 15 degrees of bilateral internal rotation of the hips. The focus detector distance was 130 cm (cannot be altered in EOS). Patients were asked to stand in a relaxed position such that it felt natural for them.

An experienced research radiographer (Bo Mussmann) and AFB found excellent inter-rater reliability (two-way random effects for absolute agreement)[59] $ICC_{2.1}$ = 0.99 (95% CI: 0.98, 0.99) on the pelvic tilt measurements in 50 randomly selected EOS scans.

Statistical analysis

The sample size calculation was based upon two-sided paired means and the following statistical properties; alpha = 0.05 and power = 0.80. The minimal clinically important difference (MCID) for the HAGOS-PAIN subscale was estimated as 10 points (≈half a standard deviation),[89] and using a standard deviation of 20.6 points [124] resulted in a minimum of 36 patients to be included. Four additional patients were added to account for possible dropouts.

Descriptive data and fitted regression residuals from the mixed-effects linear regression model were assessed for Gaussian distribution by use of QQ-plots and frequency histograms, and statistically tested using the Shapiro-Wilk test. Data were normally distributed. A two-tailed P-value of $P \leq 0.05$ was considered statistically significant, and estimates presented with 95% confidence intervals.

Repeated measurements from a particular patient are likely to be more similar to each other than measurements from different patients, and this correlation needs to be considered in the analysis of the resulting data.[15] Furthermore, longitudinal measurements are not independent of one another, due to the individual baseline value and time factor, which also must be taken into account.[15] Accordingly, a mixed-effects linear regression model analysis was performed for each dependent variable (HAGOS subscales, EQ-5D-3L, and pelvic tilt) with time-points (T1, T2, and T3) as fixed factors framing the control period and the intervention period, and patients as a random factor. The analysis followed the Intention To Treat (ITT) principle [15], accommodating missing data under the assumption “missing at random,” and was used in the analysis of change scores following the intervention. A sensitivity analysis (per-protocol analysis) was conducted for patients demonstrating the *a priori* defined acceptable adherence to exercise (≥75%).

Feasibility was analyzed according to the potential relationship between time (the 8-week period) and (i) the ratio of patients exercising; (ii) the ratio of patients experiencing pre to post exercise-related pain (NRS >4); and (iii) the ratio of patients using analgesics, with Spearman’s Rho.

STATA/IC 16 software (StataCorp. LP, College Station, TX, USA) was used to perform statistical analyses.

*Post hoc analysis*

A responder analysis was carried out to offer an additional clinical interpretation of the primary outcome due to the heterogeneous results.[33] Thus, change in HAGOS-PAIN was investigated for the exercise period (T3 minus T2 scores) versus pre-exercise (T2) outcome values (HAGOS-PAIN*,* pelvic tilt, age, and BMI). The non-parametric Mann-Whitney U-test was used to test for potential differences in median HAGOS-PAIN change scores between the three intervals of pre-exercise HAGOS-PAIN scores (<1st quartile vs. IQR, and IQR vs. >3rd quartile).

Selection of subsample for physical performance assessment

A subsample (20 patients) of the included patients was randomly selected to be investigated for change in; isometric hip muscle-strength using stabilized dynamometry (flexion, extension, and abduction); isometric abdominal muscle-strength using hand-held dynamometry; kinematic and kinetic outcomes during gait and functional tasks (counter-movement jump and squat) in a 3-dimensional motion capture laboratory; range-of-motion (hip extension and lumbar flexion); and the single-leg hop for distance test. These explorative outcomes on physical performance and dynamic pelvic tilt will be reported in secondary analyses not specified in the current PhD thesis.

## 9. SUMMARY OF RESULTS

### 9.1. Study I. Systematic review of the literature

Four studies were included in the final qualitative synthesis (**Figure 5**).

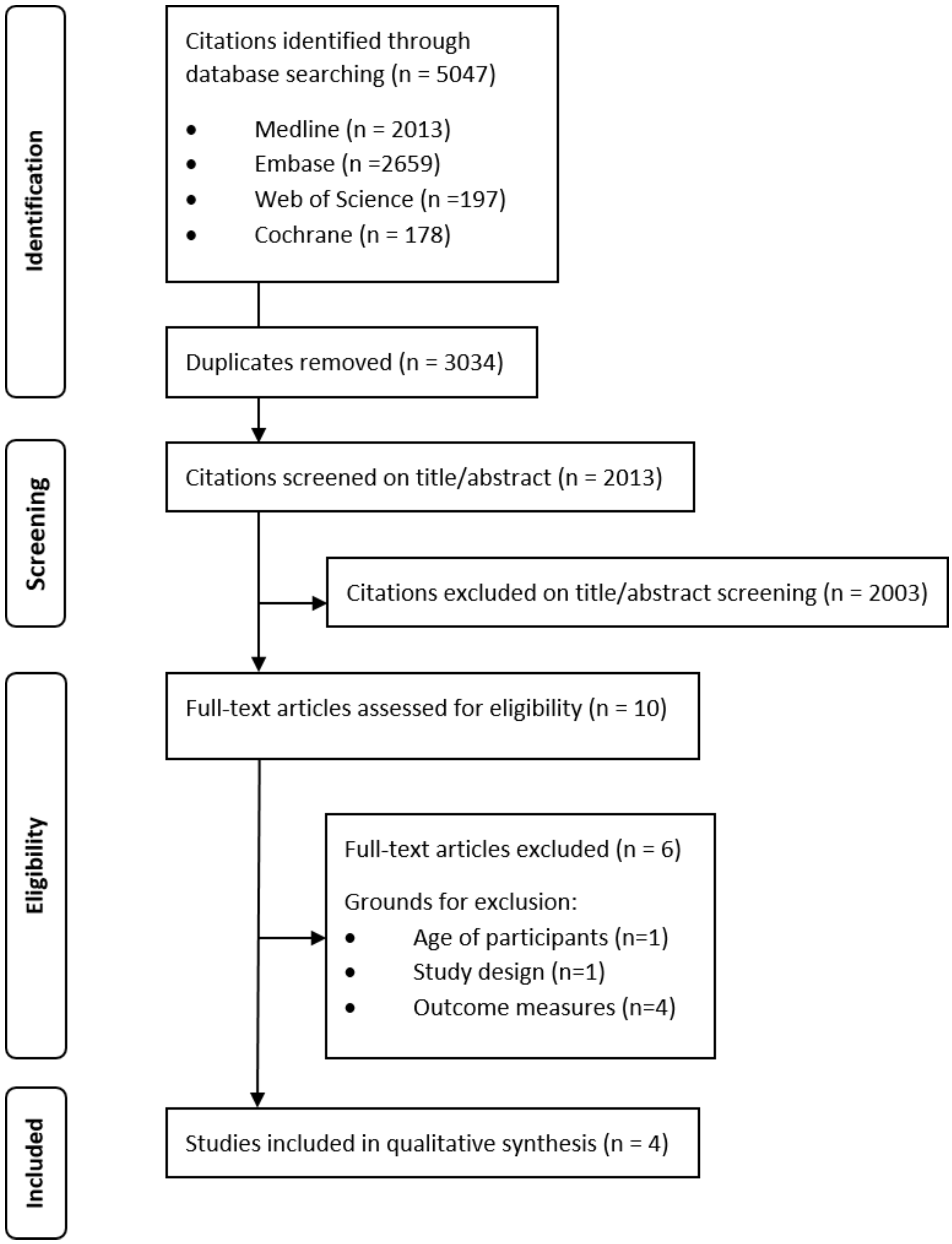


**Figure 5.** Summary of search strategy results

The included studies were; two RCT´s (both studies on non-symptomatic populations), and two intervention studies without control (one study included patients with low back pain, and the other study included patients with sacroiliac joint pain). In total, these four studies comprised 95 patients. For further details please, see Brekke et al 2020 (Paper I).[23] One RCT demonstrated a significant reduction in anterior pelvic tilt, and the two non-RCT´s demonstrated a significant reduction in symptoms in combination with a significant reduction in anterior pelvic tilt. Overall risk of bias across both the RCT´s and non-RCT´s were rated as *High*. Inspired by the GRADE approach, the overall quality and certainty of evidence on the effect of non-surgical treatment in reducing excessive anterior pelvic tilt in adults was graded as *Very low*.

### 9.2. Study II. Radiographic case-control study

In the study group, a total of 111 patients (111 pelvises / 222 hips) and a total of 132 controls (132 pelvises / 264 hips) were included. Matching controls were not successful for the youngest age group (20–25 years); thus, 75 females and 15 males were missing for complete matching (**Figure 6**) (**Table 1**).

Image quality was assessed in all the included radiographs to ensure complete data for equal comparison between the groups. Hence, 101 pelvises / 208 hips and 132 pelvises / 263 hips remained for analysis for the study and control groups, respectively.

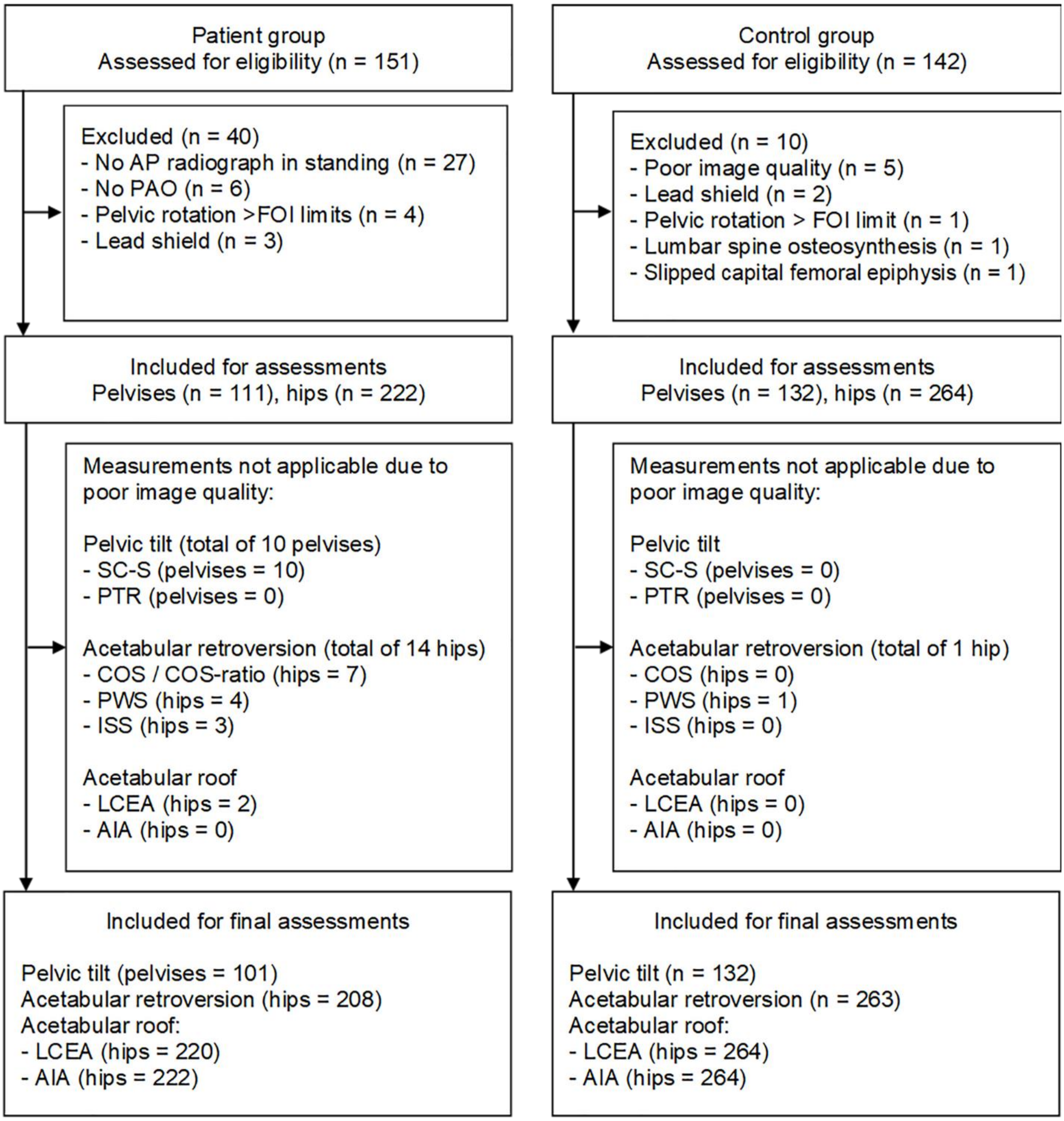


**Figure 6.** Flow diagram for eligibility assessment and inclusion of participants

**Table 1. Between-group differences in participant characteristics and matching**

| | Patients | General population | Δ group [a] | p-value |
|---|---|---|---|---|
| Characteristics | | | | |
| Sex, n (F/M) (%) | 111 (83/28) (75/25) | 132 (91/41) (69/31) | | 0.32 [b] |
| Age, years, Median (IQR) | 24 (22–29) | 29 (25–35) | -5 | <0.01 [c] |
| BMI, kg/m$^2$, Median (IQR) | 24 (21–27) | 23 (21–24) | 1 | 0.01 [c] |
| SC-S (mm), females, Median (IQR) | 58 (49–65) | 42 (31–52) | 16 | <0.001 [c] |
| SC-S (mm), males, Median (IQR) | 36 (30–50) | 22 (2–31) | 14 | <0.001 [c] |
| PTR, females, Median (IQR) | 0.31 (0.26–0.34) | 0.39 (0.33–0.48) | -0.08 | <0.001 [c] |
| PTR, males, Median (IQR) | 0.36 (0.30–0.43) | 0.47 (0.40–0.61) | -0.11 | <0.001 [c] |
| Matching | | | | |
| 20-25 yr. n (F/M) | 64 (49/15) | 38 (23/15) [d] | | 0.09 [b] |
| 26-30 yr. n (F/M) | 21 (12/9) | 42 (24/18) | | |
| 31-35 yr. n (F/M) | 12 (10/2) | 24 (20/4) | | |
| 36-40 yr. n (F/M) | 14 (12/2) | 28 (24/4) | | |

[a] Median difference, [b] Chi-square test, [c] Wilcoxon rank-sum test, [d] Incomplete matching 2 (controls):1 (patient), no statistical difference in the distribution of sex (p = 0.09).
Δ: difference, n: numbers, F/M: females/males, %: percent, IQR: interquartile range, BMI: body mass index, SC-S: vertical distance between the sacrococcygeal joint and the upper edge of the symphysis, mm: millimeters, PTR: pelvic tilt ratio.

Between-group differences in pelvic tilt

The study group had significantly larger median anterior pelvic tilt of 14.3 mm (95% CI: 8.9–19.6) in the *sacrococcygeal joint–symphysis distance* and -0.08 (95% CI: -0.11– -0.04) in *pelvic-tilt-ratio* compared to the control group (**Table 2**).

**Table 2. Between-group differences in pelvic tilt measured by two methods.**

| | Patients n = 101, F/M (74/27) Median (IQR) | General population n = 132, F/M (91/41) Median (IQR) | Unadjusted median difference [a] (95% CI) | Adjusted median difference [b] (95% CI) |
|---|---|---|---|---|
| Methods: | | | | |
| 1) SC-S (mm) | 54 (39–65) | 35 (20.5–49) | 19 (13.2–24.8) * | 14.3 (8.9–19.6) * |
| 2) PTR | 0.32 (0.26–0.35) | 0.41 (0.34–0.52) | -0.09 (-0.12– -0.05) * | -0.08 (-0.11– -0.04) * |

[a] Nonparametric regression model, [b] Nonparametric regression model adjusted for age, BMI, and sex.
* P <0.001, n: numbers, F/M: females/males, IQR: interquartile range, 95% CI: 95 percent confidence interval, mm: millimeters, SC-S: vertical distance between the sacrococcygeal joint and the upper edge of the symphysis, PTR: pelvic tilt ratio.

Prevalence of acetabular retroversion

All 111 patients in the study group had retroversion in either of the hips or bilaterally. A total of 32 out of 132 controls (24%) (19 females [59%], 13 males [41%]) had acetabular retroversion (unilateral/bilateral: 16/16). The study group had significantly higher prevalence of hips with acetabular retroversion (COS+PWS) (73% vs. 18%, p <0.01) compared to the control group (**Table 3**).

**Table 3. Between-group differences in radiographic signs of acetabular retroversion**

| | Patients | General population | Δ group | p-value |
|---|---|---|---|---|
| Radiographic signs | | | | |
| Prevalence – hips | n = 208, y/n (yes %) [a] | n = 263, y/n (yes %) [b] | | |
| COS | 198/10 (89) | 84/179 (32) | 57 [c] | <0.01 [d] |
| PWS | 167/41 (80) | 60/203 (23) | 57 [c] | <0.01 [d] |
| ISS | 153/55 (74) | 65/198 (25) | 59 [c] | <0.01 [d] |
| **COS+PWS**, acetabular retroversion | **163/45 (73)** | **48/215 (18)** | 55 [c] | <0.01 [d] |
| COS+PWS+ISS | 132/76 (59) | 36/227 (14) | 45 [c] | <0.01 [d] |
| COS-ratio, Median (IQR) | 0.27 (0.2–0.36) | | | |
| Acetabular retroversion | | | | |
| Prevalence – subjects | n = 111 (100%) (PAO) | n = 32 (24%) (COS+PWS) | | |
| n (unilateral/bilateral) (%) | 79/32 (71/29) | 16/16 (50/50) | | |
| Sex, n (F/M) (%) | 83/28 (75/25) | 19/13 (59/41) | | |
| Acetabular roof | | | | |
| LCEA (°), [n = hips] Median (IQR) | [220], 28.5 (24–34) | [264], 30 (25–34) | -1.5 [e] | 0.14 [f] |
| AIA (°), [n = hips] Median (IQR) | [222], 4 (1–8) | [264], 5 (0–8) | -1 [e] | 0.85 [f] |

[a] 14 hips were removed due to poor image quality, [b] One hip was removed due to poor image quality, [c] Percentage points difference, [d] Chi-square test, [e] Median difference, [f] Wilcoxon rank-sum test.
Δ: difference, n: numbers, y/n: yes/no, %: percent, COS: cross-over sign, PWS: posterior wall sign, ISS: ischial spine sign, IQR: interquartile range, PAO: diagnosed with acetabular retroversion and operated with periacetabular osteotomy, F/M: females/males, LCEA: lateral center-edge angle, AIA: acetabular index angle, °: degrees.

Data sharing

Data will be publicly available in an open access repository with Mendeley Data at http://dx.doi.org/10.17632/x5m4zgfx5s.1 (DRAFT)

A preview can be found at https://data.mendeley.com/datasets/x5m4zgfx5s/draft?a=3aea7182-f382-441a-a0c4-93dd695eeb08

### 9.3. Study III. Feasibility and intervention study

Out of 42 included patients (39 women, 93%) (mean age of 22.2 ± 4.2 years, (**Table 4**), 39 (93%) completed the exercise intervention (**Figure 7**).

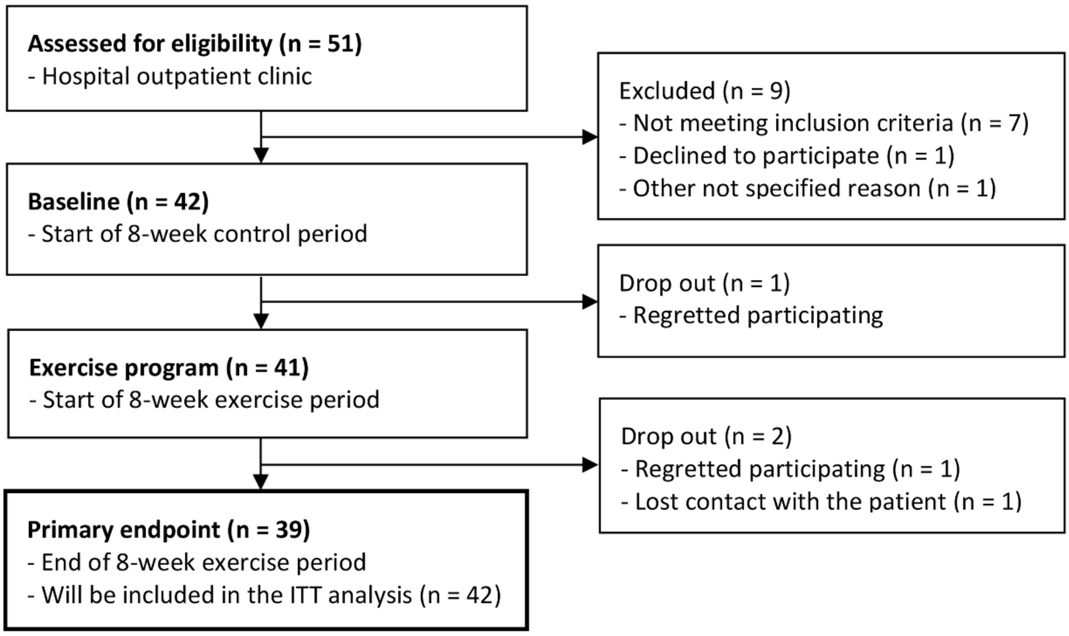


**Figure 7**. Flow diagram of patients´ progress through the study

**Table 4**. Descriptive statistics at baseline (n = 42)

| | |
|---|---|
| **Patient characteristics** | |
| Sex, female, n (percent) | 39 (93) |
| Age, years | 22.2 ± 4.2 |
| BMI, kg/m$^2$ | 23.1 ± 4.6 |
| Height, m | 1.69 ± 0.1 |
| Weight, kg | 66.4 ± 13.3 |
| Affected hip, n (percent) | |
| None | 1 (2) |
| Bilateral | 12 (29) |
| Left | 11 (26) |
| Right | 18 (43) |
| **PROM** | |
| HAGOS, subscales | |
| Pain | 59 ± 19.8 |
| Symptoms | 57.3 ± 17.5 |
| Physical function in daily living | 64.8 ± 22.5 |
| Physical function in Sport and Recreation Participation in | 56.7 ± 24.7 |
| Physical Activities | 47.9 ± 32.3 |
| Hip and/or groin-related Quality of Life | 40.8 ± 23.3 |
| EQ-5D-3L | 0.69 ± 0.2 |
| **Pelvic tilt** | |
| Pelvic tilt, degrees | 74.3 ± 8.4 |

Values are mean ± (standard deviation) unless otherwise indicated.
Abbreviations: n (numbers), BMI (body mass index), PROM (patient-reported outcome measure), IQR (interquartile range), SD (standard deviation), HAGOS (The Copenhagen Hip and Groin Outcome Score), EQ-5D-3L (European Quality of Life-5 Dimensions-3 Levels index value)

Feasibility

Variables related to feasibility of the exercise intervention demonstrated the following (i) Dropout: n = 3, (7%). (ii) Acceptable adherence to exercise: n = 33, (85%). (iii) Ratio of training sessions increasing pre- to post-exercise-related pain (NRS >4): Decreased from 35% in week 1 to 18% in week 8 ($r$ = -0.79, p = 0.02). (iv) Exercise-related adverse events: Non-serious adverse events. However, pain/discomfort (NRS >4) occurred in the following exercises; strengthening the hip abductors (n = 13), strengthening the hip external rotators (n = 13), movement control in lying "dying bug" (n = 4), and three patients reported delayed onset (2–3 hours after exercise) hip joint pain. (v) Patients using hip-related analgesics, decreased from 29% in week 1 to 12% in week 8 ($r$ = -0.90, p <0.01).

Exercise-related changes

*Primary outcome*

The intervention period demonstrated a non-significant improvement in mean HAGOS-PAIN of 5.2 points (95% CI: -0.3–10.6) in comparison with the control period (p = 0.06) (**Table 5**).

*Secondary outcomes*

Of the remaining HAGOS subscales, only symptoms showed a significant mean between-periods improvement of 6.2 points (95% CI: 0.2–12.3), (p = 0.04). Furthermore, no changes were observed for the EQ-5D-3L score nor the degree of pelvic tilt (**Table 5**).

*Per-protocol analysis*

The per-protocol analysis confirmed the ITT analysis, as no differences in change scores were identified (**Table 5**).

**Table 5**. Outcome change scores

| | Control-period change | Exercise-period change | Between-periods change |
|---|---|---|---|
| **Primary outcome** | | | |
| **HAGOS *pain*–subscale** | | | |
| ITT | 0.4 (-2.7–3.5) | **5.6 (2.4–8.8) **** | 5.2 (-0.3–10.6) |
| PP | 0.4 (-3.1–3.9) | **5.3 (1.8–8.8) **** | 4.9 (-1.2–11.0) |
| **Secondary outcomes** | | | |
| **HAGOS, *subscales*:** | | | |
| *Symptoms* | | | |
| ITT | -1.0 (-4.5–2.5) | **5.2 (1.7–8.8) **** | **6.2 (0.2–12.3) *** |
| PP | -2.0 (-6.0–2.0) | **6.9 (2.9–11.0) **** | **8.9 (1.9–15.9) **** |
| *ADL* | | | |
| ITT | 3.6 (-0.5–7.8) | 3.6 (-0.6–7.9) | -0.02 (-7.3–7.3) |
| PP | 3.3 (-1.2–7.8) | 4.2 (-0.3–8.7) | 0.9 (-6.9–8.7) |
| *Sport/Rec* | | | |
| ITT | 2.0 (-2.0–6.0) | **6.1 (2.0–10.2) **** | 4.1 (-2.9–11.1) |
| PP | <0.1 (-4.1–4.1) | **6.7 (2.6–10.9) **** | 6.7 (-0.4–13.9) |
| *Physical Activities* | | | |
| ITT | 2.4 (-3.2–8.1) | 0.7 (-5.1–6.5) | -1.7 (-11.6–8.2) |
| PP | -1.1 (-7.1–4.8) | 3.8 (2.1–9.7) | 4.9 (-5.3–15.2) |
| *Quality of Life* | | | |
| ITT | 1.1 (-2.4–4.6) | 2.8 (-0.8–6.3) | 1.7 (-4.5–7.8) |
| PP | -0.3 (-4.1–3.5) | 3.5 (-0.3–7.3) | 3.8 (-2.7–10.3) |
| **EQ–5D–3L** | | | |
| ITT | 0.02 (-0.01–0.06) | 0.01 (-0.03–0.04) | -0.02 (-0.09–0.05) |
| PP | 0.02 (-0.02–0.06) | <0.01 (-0.04–0.04) | -0.02 (-0.09–0.05) |
| **Pelvic tilt, degrees** | | | |
| ITT | -0.4 (-1.7–0.9) | **-2.0 (-3.3– -0.6) **** | -1.6 (-3.9–0.7) |
| PP | -0.5 (-1.9–1.0) | -1.4 (-2.9– 0.1) | -0.9 (-3.4–1.6) |

Mixed-effects linear regression model adjusted for baseline values. ITT (n = 42), PP (n = 33).
Data are expressed as mean (95% CI), *p <0.05, and ***P* <0.01
Abbreviations: ITT (intention to treat), PP (per protocol, ≥75% exercise adherence), HAGOS (The Copenhagen Hip and Groin Outcome Score), ADL= Physical function in daily living, Sport/Rec= Physical function in Sport and Recreation, Physical Activities= Participation in Physical Activities, Quality of Life= hip and/or groin-related Quality of Life, EQ-5D-3L (European Quality of Life-5 Dimensions-3 Levels index value.

*Post hoc analysis*

A median HAGOS-PAIN change score of 7.5 points (IQR: 0–12.5) in the pre-exercise IQR was significantly larger than the median scores of 2.5 points (IQR: 0–5) (p = 0.04) and -1.25 points (IQR: -3.75–3.75) (p = 0.01) for Q1 and Q3, respectively (**Figure 8**). Additionally, 10 out of 11 patients who responded positively (≥MCID) to the exercise intervention (n = 10, 26%), had a pre-exercise HAGOS-PAIN score within the IQR (between 47.5 to 70 points). A similar responder finding to the exercise intervention was not shown for pelvic tilt, age, or BMI.

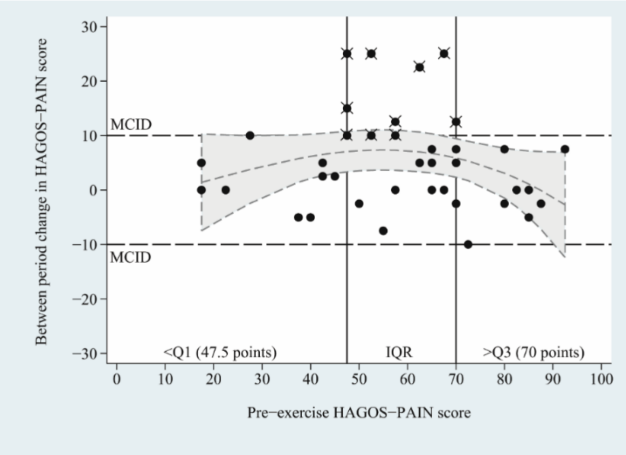


**Figure 8**. Change in HAGOS pain-subscale score post-exercise against pre-exercise HAGOS pain-subscale score. The horizontal dashed lines mark the Minimal Clinical Important Difference (MCID) of ± 10 points in the HAGOS-PAIN subscale. The vertical solid lines mark the first quartile (Q1), the third quartile (Q3), and the in-between interquartile range (IQR). The grey area marks the 95% CI of the fitted regression line (grey center dashed line). Patients with positive or negative HAGOS-PAIN change scores (≥10 points) are defined as positive or negative responders, respectively. Ten of the eleven patients responding positively to exercise had pre-exercise HAGOS-PAIN scores within the IQR (marked with an X). Some observations are superimposed; thus, there is a discrepancy between the actual number (n = 39) and observations seen in the figure.

Data sharing

Data were made publicly available in an open access repository with Mendeley Data at http://dx.doi.org/10.17632/h4bmjrs7gc.2

Supplementary results not reported in manuscript III

To be able to compare and discuss the degree of pelvic tilt for patients in study II with patients in study III, the *sacrococcygeal joint-symphysis distance* and *pelvic-tilt-ratio* were measured on the frontal EOS scan in study III (**Table 6**). Additionally, pelvic incidence, sacral slope, and pelvic tilt were measured on lateral EOS scans in study III to be able to discuss the pelvic anatomic parameters proposed related to pelvic sagittal balance regulation[66, 68] (**Table 6**).

**Table 6**. Supplementary results

| | Patients (study III) | Reference values (Pierannunzii et al)[93] |
|---|---|---|
| Pelvic tilt, median (IQR) | | |
| SC-S (mm), females (n = 34) | 56.5 (50–68) | |
| SC-S (mm), males (n = 3) | 26 (11–44) | |
| PTR, females (n = 38) | 0.26 (0.19–0.28) | |
| PTR, males (n = 38) [c] | 0.35 (0.24–0.44) | |
| | | |
| Pelvic parameters (n = 42) | | |
| Pelvic incidence (degrees) ±SD | 42 ± 9.5 | 55.1 ± 9 |
| Sacral slope (degrees) ±SD | 42.2 ± 8.4 | 41.2 ± 7 (accounting for 76% of PI) |
| Pelvic tilt (degrees) ±SD | -0.2 ± 8.1 | 12 ± 6.4 (accounting for 24% of PI) |

IQR: interquartile range, SC-S: vertical distance between the sacrococcygeal joint and the upper edge of the symphysis, PTR: pelvic tilt ratio, COS: cross-over sign, PI: pelvic incidence

* Non-significant difference in COC-ratio between symptomatic and non-symptomatic hips (P = 0.32), unpaired, two-tailed t-test.

## 10. DISCUSSION

### 10.1. Key findings

The overall aim of the thesis was to investigate a potential alternative to surgery for patients with symptomatic acetabular retroversion regarding symptoms, function, and pelvic tilt. The systematic review demonstrated that only a few studies – of low quality – have investigated the effect of non-surgical interventions targeting normalization of excessive anterior pelvic tilt. Furthermore, only one study was an exercise intervention, which is recommended to be included in physiotherapist-led interventions. Therefore, there was a need to develop and test an exercise intervention targeting patients with symptomatic acetabular retroversion and excessive anterior pelvic tilt. The need for testing such a targeted intervention was confirmed by the finding of increased anterior pelvic tilt in patients prior to PAO, compared to a control group randomly selected from the general population. Therefore, excessive anterior pelvic tilt should be considered when treating patients with acetabular retroversion, as pelvic tilt may further exacerbate symptoms. The 8-week home-based intervention did not demonstrate a clinically relevant improvement in hip-related pain. However, the ratio of patients using analgesics decreased significantly over the exercise period, and a post hoc responder analysis revealed that patients with moderate pain at baseline might benefit from this exercise. No statistical or clinically relevant change in anterior pelvic tilt was observed.

### 10.2. Study findings and current evidence

*Systematic review of the literature*

Suggested therapeutic treatments to reduce excessive anterior pelvic tilt are described in textbooks in the field of physical therapy, training, and rehabilitation.[56, 67, 74, 90, 103, 135] However, the study identified a gap in research with few studies of low-quality designs and no overall evidence in the effect of non-surgical interventions – including exercise therapy – in normalizing anterior pelvic tilt and potentially related symptoms. During the study selection process, screening titles and abstracts, the majority of studies related to pelvic tilt were cross-sectional designs,[26, 36, 88, 129, 136] and only a few prospective interventions. Although, there is no evidence that excessive anterior pelvic tilt is an isolated clinical disorder, it is commonly suspected of causing unspecific low back pain and pelvic girdle pain. [11, 47, 53, 54, 104] Therefore, we suggest that excessive anterior pelvic tilt should be addressed as a specific condition on an individual level potentially related to or enhancing symptoms. Thus, high methodologically quality interventions targeting specific types of impairments, biomechanically related to, and in combination with excessive anterior pelvic tilt are warranted.[23]

*Radiographic case-control study*

The study identified and confirmed the observation from the outpatient clinic, that patients with symptomatic acetabular retroversion have increased anterior pelvic tilt compared to a general population.

Defining normal pelvic tilt. Normal pelvis in standing is slightly anteriorly tilted[66, 94] compared to the defined anatomical neutral pelvic tilt (i.e., a vertical pelvis with zero degrees tilt/Lewinnek´s plane).[73, 118] Normal pelvic tilt/inclination is 60–65° and equal across the sexes[108] measured as the angle between a horizontal line and a line connecting the upper border of the symphysis with the sacral promontory on a lateral radiograph. According to clinicians (e.g., physiotherapists and chiropractors), pelvic tilt is most often assessed using inclinometry in standing, measured as the angle between the line connecting ASIS (anterior superior iliac spine) and PSIS (posterior superior iliac spine) and horizontal. Normal pelvic tilt has a reference value of about 8 degrees anterior pelvic tilt across the sexes.[26, 36, 88, 96]

In lack of a lateral radiograph, considered as the gold standard for measuring the true pelvic inclination angle,[120] various methods have been proposed for measuring a surrogate pelvic tilt from anteroposterior radiographs. The *sacrococcygeal joint–symphysis distance* is the most used measurement for assessing pelvic tilt in anteroposterior radiographs.[120] However, we revealed that the *pelvic-tilt-ratio* was easily assessed compared to the *sacrococcygeal joint–symphysis distance*. To our knowledge, we are the first to report the degree of anterior pelvic tilt in a homogeneous group of patients with acetabular retroversion. Hence, a comparison is not possible. However, in study III, we also measured the *sacrococcygeal joint–symphysis distance* and *pelvic-tilt-ratio* in all patients for comparing it to the study group in study II (**Table 5**). Pelvic tilt in both study groups were not different and larger in comparison to the general population. Thus, our results on the *sacrococcygeal joint–symphysis distance* is larger compared to what was previously reported in patients evaluated for various types of FAIS.[43, 97] We have no explanation for the observed divergence, and therefore, this should be clarified in future studies. One could argue, that acetabular retroversion due to the anatomic morphology with the hemipelvises suggested externally rotated, may affect pelvic tilt, in comparison to other types of FAIS which is not affecting the entire pelvis but is a condition localized to the hip joint.

A biomechanical modal of the spinopelvic balance includes three interrelated pelvic angular parameters (*pelvic incidence*, *sacral slope*, and *pelvic tilt*).[68] In short, the *pelvic incidence angle* is a key characteristic of the pelvis, which becomes set at the end of growth. The angle is measured between a line connecting the hip joint axes, and the center of the first sacral end-plate and a line orthogonal to the first sacral end-plate. [68] The *pelvic incidence angle* is the algebraic sum of the *pelvic tilt* and *sacral slope angles,* which are inversely related during movement.[68] Importantly, the pelvic parameters *pelvic tilt angle* must be differentiated from the inclination angle, because during anterior pelvic tilt/inclination, the pelvic parameter *pelvic tilt angle* decreases, contrary to the inclination angle. The mean *pelvic incidence angle* value in asymptomatic subjects is 55 ±10 degrees.[127] In our study III, we found a mean *pelvic incidence angle* of 42.2 ±8.4 degrees (**Table 5**). Similar values of *pelvic incidence angles* (42.5 ±8.5°, and 44.9 ±11.3°), have been reported in patients with acetabular retroversion.[29, 34] Subjects with small *pelvic incidence angles* have a shorter anteroposterior pelvic diameter, which is associated with a flattened lordosis, and low ability of pelvic tilting.[9, 66, 68] Thus, our findings on patients with acetabular retroversion and excessive anterior pelvic tilt is in contrast to the proposed biomechanical model. However, no studies have reported *pelvic incidence angles* together with the degree of pelvic tilt in patients having genuine acetabular retroversion, and thus, comparing our findings is difficult. We have no explanation for the observed divergence, and consequently, this should be clarified in future studies.

*Feasibility and intervention study*

The study identified that a targeted 8-week home-based exercise intervention showed acceptable feasibility in patients with acetabular retroversion and excessive anterior pelvic tilt. However, results concerning adherence, exercise-related pain, and exercise-related adverse events were less conclusive. Overall, the study did not demonstrate statistically nor clinically significant changes in either the self-reported HAGOS-PAIN score (primary outcome) or the secondary outcome measures of function, quality of life, or pelvic positioning. However, post hoc analysis demonstrated that patients with moderate HAGOS-PAIN scores at baseline responded positively to the intervention as opposed to patients with high or low levels of pain. Moreover, a reduction in analgesic medication during the intervention period was observed, which, despite not being registered as an outcome measure, may be considered as a positive result.

Feasibility. Most exercise studies on patients with FAIS specify a supervised program with a duration of 12 weeks. [12, 32, 50, 114, 134] Good adherence to an exercise program is essential to conclude on the intervention's ability to cause a change. Conducting a home-based unsupervised exercise intervention is associated with risk of poor adherence.[20] A systematic review[20] found relatively strong evidence that the following factors are predictors for adherence in home-based exercise programs: Intention to engage in the intervention, self-motivation, self-efficacy, previous adherence to exercise, and social support. However, patients were not consulted about these prerequisites for exercising at home, which could potentially have given us insight into the expectation of adherence. If doing so, we could have taken further action, and maybe enhanced adherence to exercise towards the end of the 8-week period. This would in particular also apply to the optional 16 weeks of exercise where only three out of 21 patients continued with the program to the extent prescribed. For these 21 patients, a significant, but clinically non-relevant pain reduction (within-group median change of 7.5 (IQR: -2, 15), ($P = 0.01$), was observed (data not shown) (paper III – see Appendix C).

Intervention. Exercise-based[52] physiotherapist-led interventions[51] in patients with various types of FAIS are supported with a low to moderate level of evidence for a short-term effect.[75] Until now, no studies on non-surgical interventions have been conducted on a group of homogeneous patients with acetabular retroversion. The body of evidence on non-surgical intervention for patients with FAIS is mainly based on studies in which either the majority of participants are patients with cam-type FAIS[1, 32, 50, 91] or the type/distribution of FAIS is not reported.[19, 40, 77, 86, 114, 133] However, acetabular retroversion (pincer-type FAIS) is associated with the shape and/or orientation of the acetabulum, controlling the pelvis and thus the orientation of the acetabulum seems especially important.[49] Trunk muscle strength is recommended as an important target for people with FAIS given its important role in controlling the pelvis, and thus the orientation of the acetabulum.[49] As such, most non-surgical exercise studies in patients with

FAIS have applied protocols, including trunk muscle strengthening exercises, but with no explicit definition of pelvic control.[1, 40, 50, 91, 92, 133, 134] Therefore, we find it reasonable to suggest additional future studies investigating if a targeted exercise program, or other non-surgical intervention, are able to normalize pelvic tilt and, hence, reduce symptoms in patients with symptomatic acetabular retroversion and excessive anterior pelvic tilt. However, supervision and level of pre-exercise pain should be considered in future studies. In addition, as exercise-related adverse events were most commonly reported in hip muscle-strengthening exercises, it may be suggested that the beginning of the exercise period only consists of trunk muscle strengthening- and pelvic movement control exercises.

*Symptomatic and asymptomatic acetabular retroversion*

There is increasing evidence that acetabular retroversion represents an external rotation of the hemipelvises rather than a local hip joint pathomorphological condition.[48, 98, 121] Hence, acetabular retroversion is reported as being a bilateral condition.[58, 60, 98] Systematic reviews have reported that various asymptomatic types of pincer-type FAIS, including acetabular retroversion, are not uncommon.[24, 78] In a group of patients with bilateral retroversion, it was found that 64% of the hips with retroversion caused symptoms, and the rest were asymptomatic.[98] We found similar ratios between symptomatic and asymptomatic hips in study III (70% symptomatic vs. 30% asymptomatic hips, respectively) (**Table 5**). Further, our findings on similar COS-ratios in symptomatic and asymptomatic hips (34% vs. 31%, respectively) support that acetabular retroversion is a bilateral condition. A proposed explanation for hips with acetabular retroversion being asymptomatic is individual dynamics in relation to the particular pelvic posture, and type and level of activity (i.e., mode of use of each leg).[98] In symptomatic patients, a COS-ratio of ≥30% together with posterior wall sign and ischial spine signs are suggested as indications for PAO.[109] However, it is important to take anterior pelvic tilt into consideration when diagnosing and treating patients with acetabular retroversion due to the relationship between the COS-ratio and degree of anterior pelvic tilt, and thus the risk of having symptoms related to FAIS.

## 10.3. Strength and limitations of the applied methods

*Systematic review of the literature*

The strengths of this systematic review include; a study protocol that was made publicly available a priori ensuring methodological transparency, a sensitive systematic search to maximize identification of all relevant published studies, and usage of recognized quality assessment tools. Further, experts on conducting systematic reviews – a professor in evidence-based medicine and a research librarian qualifying the search strategy – were part of the systematic review team.

This review was limited by; the paucity of studies in this research area and thus a lack of a meta-analysis, plus the heterogeneity in study methods, populations, and types of intervention. Further, only one author (AFB) screened titles and abstracts for potentially eligible studies. This increases the chance of missing potential eligible studies. However, all citations were systematically assessed using the Covidence software for systematic review management, which considerably limits this risk.

*Radiographic case-control study*

The study group was identified by screening all patients for eligibility who were operated with a PAO due to acetabular retroversion, in the period from the first operation was conducted up to the end of the data collection. However, if the current study had been a multi-center study, more patients could have been included and it could have been possible to compare results between centers; hence, generalizability would have increased. Regarding the control group, this study was the first to report a random population-based prevalence of hips with acetabular retroversion in the general population. Finding a control group with pelvic radiographs from the general population is not easy as X-rays pose a health risk, especially due to radiation of the gonads[7] and are therefore primarily used to diagnose possible disease and not a control group. Furthermore, the pelvic radiographs were taken in the functional weight bearing standing position, and not in supine position, as done in previous studies reporting a prevalence of 4–7%[22, 132] hips with acetabular retroversion when pelvises exhibiting excessive anterior pelvic tilt were excluded. This reporting on the prevalence of genuine acetabular retroversion may have limited use in a clinical setting, as hip-related symptoms are associated with radiographic signs of acetabular retroversion, regardless if they are derived from genuine acetabular retroversion, excessive anterior pelvic tilt, or a combination.[69] Firstly, trauma patients are most likely sedated, which in the supine position flattens the lumbar lordosis due to muscle relaxation (i.e., decreases the level of anterior pelvic tilt). Secondly, in the case of the awake patient, the supine position tends to increase anterior pelvic tilt compared to the standing position.[35, 97] Thirdly, excluding participants with excessive anterior pelvic tilt will decrease the prevalence of radiographic signs of acetabular retroversion as anterior pelvic tilt is positively associated with radiographic signs of acetabular retroversion.[100, 108] Further strengthening the methodology, was an author-team comprising two experienced orthopaedic surgeons, an experienced radiologist, amongst others, with expertise in PAO.

The study was limited by not being able to perfectly match the study group to the control group. However, this was adjusted for in the statistical analysis. We used different types of radiographs and measurement tools for digital and analog radiographs for the patient group and control group, respectively. Further, no reliability assessment was conducted on the control group radiographs. However, as previously described, there is no reason to believe the results are biased. No causality can be drawn from this observational cross-sectional study on the relationship between symptomatic acetabular retroversion and pelvic tilt. Although the study group is limited by originating from a single-center only, we find the generalizability acceptable. All patients who received a PAO as a result of acetabular retroversion in a period of 11 years (2007 to 2018) were assessed for eligibility and, thus, current analyses are not based on a selected group. Finally, patients with acetabular retroversion are referred to Odense from a large geographic area and, thus, most likely representing a general Danish patient having symptomatic acetabular retroversion.

*Feasibility and intervention study*

The strengths of this feasibility and intervention study include a priori defined and registered hypothesis testing with a sufficient sample size. A scoping review from 2010[2] found that 81% of published pilot/feasibility studies had insufficient sample sizes. Further, methodological transparency was provided through the study protocol made publicly available prior to patient enrollment. To ensure thorough reporting, the exercise intervention was described according to the TIDieR[38] and CERT[113] checklists for reporting interventions. The content of the targeted exercise intervention is consistent with recommendations from a recent literature review[79] of non-operative management of individuals with non-arthritic hip pain, and international consensus recommendations for hip-related pain and FAIS.[31, 52] Additionally, reliable and validated subjective (PROMS) and objective (EOS scan) outcome measures, were used. Finally, the author-team consisted of expertise in testing and conducting exercise therapy in patients with musculoskeletal dysfunction, orthopaedic surgery (PAO), and radiology (EOS).

The feasibility part of the study was limited by not systematically evaluating: the recruitment strategy, the level of quality for the home-based performance of the exercises, the motivation to persistently exercise unsupervised, and eligibility criteria. Concerning eligibility criteria, it has been proposed that the level of hip pain for the current patient group should be reduced by a period of discontinuation of sports and other strenuous activities before beginning exercising. [71, 92] This is contrary to current pragmatic methodology as we wanted to reflect a realistic clinical scenario where exercise therapy was offered to symptomatic patients not eligible for PAO without limiting their activities of daily living. Thus, the probability of achieving a clinically relevant change was potentially lowered. On the other hand, by including the per-protocol analysis, it can be suspected that patients experiencing severe pain may discontinue exercising, and thus not achieve acceptable adherence to exercise (≥75%) and/or reduced benefits as observed for the post hoc responder analysis on those patients (>3rd quartile) experiencing most pre-exercise pain. An exclusion criterion was *pelvic-tilt-ratio* greater than 0.5,[107] indicating posterior pelvic tilt. Thus, one could argue that a *pelvic-tilt-ratio* close to 0.5 in patients is not excessive. Hence, these patients will have less capability to reduce anterior pelvic tilt, and thus a small likelihood of experiencing change following the exercise program. The major limitation is the non-randomized study design, and consequently, no clear causality can be drawn from the current study design. Hence, performance bias may inflate the estimated impact of the subjective outcomes, as the patients were aware of the purpose of the intervention. Furthermore, the study was limited by a short intervention period. However, the patients were encouraged to continue with the exercise program for an additional 16 weeks after completing the 8-week exercise period. Moreover, unsupervised exercise may be considered a potential limitation to the study, although no reviews or recommendations have been published for patients with FAIS documenting this. To allow additional guidance/non-mandatory supervision for the patients, we provided the option of a booster session.

## 11. CONCLUSION

Overall, the thesis demonstrated that patients with symptomatic acetabular retroversion have an increased degree of anterior pelvic tilt (**study II**), which should be considered in the treatment, as pelvic tilt may further exacerbate symptoms. A prospective targeted exercise intervention on patients with acetabular retroversion and excessive anterior pelvic tilt did not lead to clinically relevant changes (**study III**). Thus, the present study supports current literature, showing no evidence for the effect of nonsurgical treatment in reducing excessive anterior pelvic tilt and potentially related symptoms in patients with symptomatic acetabular retroversion (**study I**).

Study I. Systematic review of the literature

Due to limited literature and in general low-quality designs, no overall evidence for the effect of non-surgical treatment in reducing excessive anterior pelvic tilt and potentially related symptoms was found.

Study II. Radiographic case-control study

We found that patients with symptomatic acetabular retroversion have increased anterior pelvic tilt compared to a control group from the general population. Moreover, we found that radiographic signs of acetabular retroversion were highly prevalent in the general population with a higher frequency in females.

Study III. Feasibility and intervention study

The 8-week home-based exercise intervention was feasible in patients with acetabular retroversion and excessive anterior pelvic tilt. However, improvements in supervision and duration of the intervention should be considered. No clinically relevant improvement in self-reported hip-related pain, function, or quality of life was observed, nor was any significant reduction in excessive anterior pelvic tilt. However, post hoc responder analysis revealed that patients with moderate pain might benefit from this type of exercise program.

## 12. PERSPECTIVES AND CLINICAL IMPLICATIONS

Clinically we meet young patients with non-arthritic hip joint pain related to FAIS which may be explained by cam or pincer-type impingement. Pincer-type FAIS is related to acetabular retroversion. Radiographic signs of acetabular retroversion may be due to genuine acetabular retroversion and/or anterior pelvic tilt. Symptoms in patients with acetabular retroversion may be further exacerbated by anterior pelvic tilt. We found increased anterior pelvic tilt in patients with symptomatic acetabular retroversion, compared to the general population. Consequently, pelvic tilt should be diagnosed and considered when treating patients with acetabular retroversion, as it may influence indication for surgery. Furthermore, radiographic acetabular retroversion was highly prevalent in the general population, which should be taken into considerations when diagnosing patients with hip-related pain. Therefore, there is a need for developing non-surgical interventions targeting a normalization of excessive pelvic tilt. It may be important to assess lumbar spine flexion- and hip extension flexibility in patients, as done in the current intervention, and not focusing only on muscle strengthening exercises, as short surrounding periarticular soft tissues may maintain an inappropriate excessive anterior pelvic tilt posture. Exercise-based physiotherapist-led interventions in patients with various types of FAIS are supported with low to moderate level of evidence. Studies on such interventions often include trunk muscle strengthening exercises, but with no explicit definition of pelvic control. Thus, defining the direction of pelvic control (i.e., towards posterior pelvic tilt to normalize excessive anterior pelvic tilt) and targeting exercises to a specific condition may enhance the impact of exercise interventions. Our targeted intervention on decreasing excessive anterior pelvic tilt did not demonstrate a clinically relevant improvement in hip-related pain. However, the study had some limitations, which may have decreased the impact of the intervention. Still, some patients benefited from the intervention, and thus we find it reasonable to suggest, a progressive physiotherapist-led targeted exercise and activity modification program in patients with acetabular retroversion and excessive anterior pelvic tilt, as a potential non-surgical alternative before a possible PAO.

It still remains to be elucidated in future research if excessive anterior pelvic tilt is a posture characteristic related to genuine acetabular retroversion and the potential underlying biomechanics. Future high-quality interventions are warranted investigating the effect of non-surgical treatment in reducing excessive anterior pelvic tilt and potentially related symptoms. Furthermore, there is a need for future studies to clarify if a targeted exercise program may reduce symptoms and/or excessive anterior pelvic tilt in patients with acetabular retroversion, and thus may be an effective alternative to surgery.

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# 14. PAPERS

## 14.1. Paper I. Systematic review of the literature

Hip

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# Non-surgical interventions for excessive anterior pelvic tilt in symptomatic and non-symptomatic adults: a systematic review

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- Excessive anterior pelvic tilt is suspected of causing femoroacetabular impingement, low back pain, and sacroiliac joint pain. Non-surgical treatment may decrease symptoms and is seen as an alternative to invasive and complicated surgery. However, the effect of non-surgical modalities in adults is unclear. The aim of this review was to investigate patient- and observer-reported outcomes of non-surgical intervention in reducing clinical symptoms and/or potential anterior pelvic tilt in symptomatic and non-symptomatic adults with excessive anterior pelvic tilt, and to evaluate the certainty of evidence.
- MEDLINE, EMBASE, Web of Science and Cochrane (CENTRAL) databases were searched up to March 2019 for eligible studies. Two reviewers assessed risk of bias independently, using the Cochrane Risk of Bias tool for randomized trials and the ROBINS-I tool for non-randomized studies. Data were synthesized qualitatively. The GRADE approach was used to assess the overall certainty of evidence.
- Of 2013 citations, two randomized controlled trials (RCTs) ($n$ = 72) and two non-RCTs ($n$ = 23) were included. One RCT reported a small reduction (< 2°) in anterior pelvic tilt in non-symptomatic men. The two non-RCTs reported a statistically significant reduction in anterior pelvic tilt, pain, and disability in symptomatic populations. The present review was based on heterogeneous study populations, interventions, and very low quality of evidence.
- No overall evidence for the effect of non-surgical treatment in reducing excessive anterior pelvic tilt and potentially related symptoms was found. High-quality studies targeting non-surgical treatment as an evidence-based alternative to surgical interventions for conditions related to excessive anterior pelvic tilt are warranted.


**Keywords:** femoroacetabular impingement; non-surgical interventions; pelvic tilt

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## Introduction

Excessive anterior pelvic tilt is a position of the pelvis in a standing posture where the tilt is larger than what is considered normal. Pelvic tilt measurements obtained from radiographic imaging are used in surgical planning and research assessments. In the clinic, pelvic tilt is measured using inclinometry as the angle between a line connecting the anterior and posterior superior iliac spine (ASIS and PSIS) and in the normal healthy population, the reference value of anterior pelvic tilt is about 8 degrees.[1–3] However, as excessive anterior pelvic tilt is not defined by a fixed cutoff point in the literature, the present study uses a definition of an anterior angle greater than 8 degrees.

Excessive anterior pelvic tilt is not an isolated clinical disorder or pathology. Nonetheless it is commonly suspected of causing unspecific low back pain (LBP) and pelvic girdle pain.[4–8] The pelvis is closely related to the hip joint as it rotates/tilts anteriorly and posteriorly, around a bicoxofemoral axis, in the sagittal plane.[9] Anterior pelvic tilt decreases normal acetabular anteversion (opening towards anterior),[10,11] which potentially may affect patients with acetabular retroversion. Acetabular retroversion is a type of developmental hip dysplasia causing an excessive anterior coverage of the femoral head and therefore potentially causing primary femoroacetabular impingement (FAI).[12] Primary FAI, which occurs as a result of morphological abnormalities (e.g. acetabular retroversion), should be distinguished from secondary FAI (e.g. excessive pelvic tilt).[13] Acetabular retroversion is associated with pain, functional limitations and early development of osteoarthritis of the hip.[14] Present curative treatment of acetabular retroversion is anterior osteoplasty or re-orientation of the acetabulum by a periacetabular osteotomy (PAO).[15,16] In the normal pelvis, without anatomical signs of acetabular retroversion, excessive anterior tilt may cause a functional positive sign of acetabular retroversion resulting in secondary FAI earlier in the arc of motion.[12,17] Thus, a reduction of anterior pelvic tilt may lead to reduced symptoms of primary and/or secondary FAI, which may have implications regarding non-surgical treatment in patients with acetabular retroversion.[17] Treatment methods focusing on reducing excessive anterior pelvic tilt are therefore of importance, and textbooks in the field of physical therapy, training, and rehabilitation[18–23] suggest various procedures in the therapeutic treatment of symptoms associated with excessive anterior pelvic tilt. Most commonly, physical training focusing on musculoskeletal correction of the postural alignment through increased muscle strength, flexibility, and functional coordinative training is suggested.[18–23] However, there seems to be a lack of evidence for the different non-surgical treatment modalities used to correct excessive anterior pelvic tilt and their potential effect on symptoms and level of pelvic tilt.

Therefore, the objective of this systematic review was to investigate the effect of non-surgical treatments in improving patient- and observer-reported outcomes related to symptoms, function and pelvic tilt in symptomatic and non-symptomatic adults, and to assess the overall certainty of evidence.

## Methods

### *Protocol and registration*

The systematic review protocol was developed in accordance with the PRSMA-P statement[24] and registered online at PROSPERO id: CRD42017056927. Literature search criteria and methods were established and agreed on by all authors.

### *Eligibility criteria*

Studies were eligible if they were non-surgical interventions aiming at reducing symptoms and/or anterior pelvic tilt in symptomatic or healthy participants over 18 years old with excessive anterior pelvic tilt.

Studies were excluded in cases with populations restricted to specific diseases or severe conditions such as neurological diseases (e.g. cerebral palsy, stroke), diseases affecting the posture (e.g. Duchenne muscular dystrophy, spondylolisthesis), degenerative conditions (e.g. spondylosis, hip osteoarthritis), intervertebral discus herniation and osteosynthesis of the lumbopelvic region. Finally, studies on pregnancy were excluded because of the naturally changed spinopelvic posture.

No language restrictions were imposed. In cases of articles reported in other languages than English or Nordic languages, Google translate would have been used.

### *Information sources*

The electronic databases MEDLINE, EMBASE, Web of Science and Cochrane Central Register for Controlled Trials (CENTRAL) were searched for relevant studies up to February 2017. The electronic search was complemented by reference tracking of the included studies. An additional search for relevant new studies added to the databases was carried out in March 2019, and yielded no further studies to be included.

### *Search*

The specific search strategy was created with input from the project team together with a Health Sciences Librarian Tove Faber Frandsen (Appendix 1).

### *Study selection*

The first reviewer (AFB) screened titles and abstracts for potentially eligible studies. Two independent review authors (AFB and AH-L) screened the full text articles for final inclusion. Disagreement was resolved through discussion. Reasons for excluding trials were recorded.

### *Data collection process*

Data item extraction was carried out by one reviewer (AFB), using a standard extraction form developed for this review. *Study* (author, year of publication, study design), *participants* (eligible criteria, sample size, age, type of impairment and symptoms), *intervention type, outcomes* (patient reported and/or observer reported), *results* and *adverse effects*.

Assessment of *patient-reported outcomes* extracted from the included studies was primary for the present study. These outcomes were: *pain* (e.g. visual analogue scale (VAS), numeric ranking scale (NRS) and questionnaire subscales), *health-related quality of life* (questionnaire subscale) and *level of function* (questionnaire subscale). Assessment of *observer-reported outcomes* was secondary. These outcomes were: *radiographs* in standing, *inclinometry* in standing and potentially *other validated measures* of pelvic tilt in standing. In case of incomplete outcome reporting, the study authors would be contacted for additional information.

### *Risk of bias in individual studies*

The risk of bias for each study was assessed independently and then discussed by two authors (AFB and AH-L) using Cochrane Collaboration's tool for assessing risk of bias in randomized controlled trials[25] and the ROBINS-I tool (Risk Of Bias In Non-randomized Studies – of Interventions).[26]

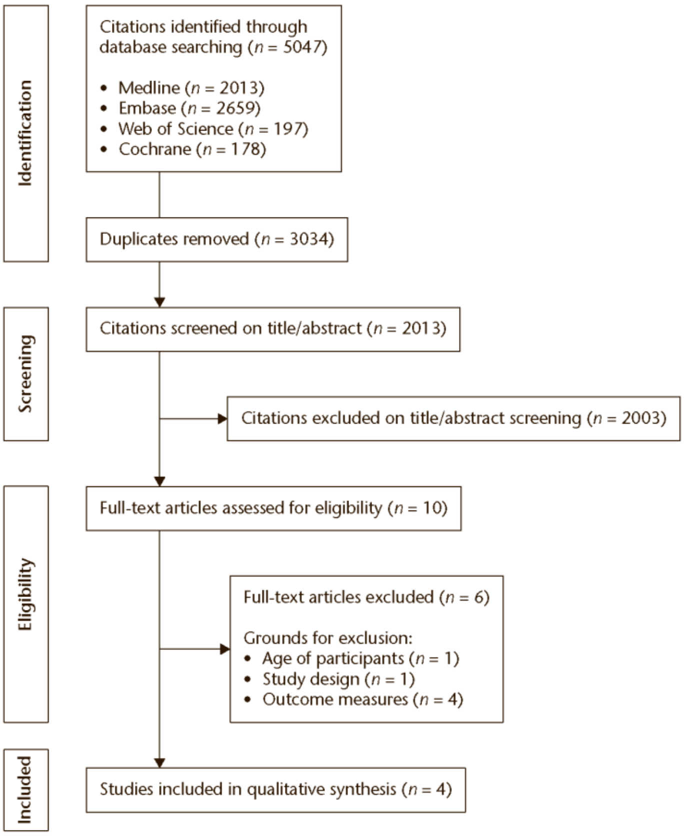


**Fig. 1** Summary of search strategy results.

In case of disagreement, a third author (AH) was consulted. The overall risk of bias across the studies for both the randomized controlled trials (RCTs) and intervention studies without control was assessed finally.

### *Synthesis of results*

Due to expected and encountered variation of study designs and heterogeneity in results, data were synthesized qualitatively. Assessment of the overall certainty of the evidence was inspired by The Grades of Research, Assessment, Development and Evaluation (GRADE) approach.[27]

## Results

### *Study selection*

Of 2013 citations, 10 full-text articles were assessed for eligibility; of those 10, four were included in the final qualitative synthesis (Fig. 1).

### *Study characteristics*

The four studies included in the final qualitative synthesis (two RCTs and two intervention studies without control) contained in total 95 patients with sample sizes ranging from 7[28] to 40 patients[29] (Table 1). Study population and type of intervention differed between all studies.

Regarding the RCT studies: Cottingham et al[30] included healthy non-symptomatic patients (32 males, mean age 27 years) having an anterior pelvic tilt exceeding nine degrees. The treatment consisted of soft tissue myofascial manipulation of the pelvic region. The immediate and 24-hour effect was assessed as the level of pelvic tilt measured using inclinometry.

Levine et al[29] included healthy non-symptomatic patients (32 females/8 males, mean age 24.5 years) having a mean anterior pelvic tilt of 8–10 degrees and abdominal muscle weakness to the extent of not being able to maintain posterior pelvic tilt during a double leg lowering

**Table 1. Characteristics of the included studies**

| Authors, year | Design | Sample* | Impairment (symptoms) | Intervention (Experiment/Control) | Outcomes (Patient/Observer) | Results | Adverse effects |
|---|---|---|---|---|---|---|---|
| Cottingham et al, 1988[30] | RCT | *n* = 32 males<br>Mean age = 27 years<br>Allocation 1:1 | Pelvic anteversion > 9°. Healthy non-symptomatic. | The immediate and 24-hour follow-up effect.<br>E: Rolfing soft tissue manipulation of the pelvic region (3 x 15 minutes). The three primary myofascial regions manipulated were the iliopsoas, deep hip rotator, and hamstring muscles.<br>C: Lying in the same positions as those receiving treatment (3 x 15 minutes), without soft tissue manipulation. | O: Inclinometry of pelvis tilt in standing defined as the angle between an ASIS/PSIS line and the horizontal plane.<br>Parasympathetic activity assessed with a *Vagal Tone Monitor* | The experimental group demonstrated immediate and 24-hour decreases of 1.7 ° (12.3 ° vs. 10.6 °) and 1.4 ° (12.3° vs. 10.9 °) (p < 0.01), respectively, in standing anterior pelvic tilt angle, and a significant increase in vagal tone. The control group did not show significant pretest-posttest differences. | No |
| Levine et al, 1997[29] | RCT | n = 40; F/M: 32/8<br>Mean age = 24.5 years<br>Exp/control group F/M distribution: NA<br>Allocation 1:1 | Healthy subjects with no LBP. Abdominal muscle weakness (Kendall double leg lowering test) | E: Eight-week (5 of 7 days) individual prescribed programme of primarily abdominal strengthening and supplementary hip/ lumbar spine stretching exercises. Supervised once a week for programme adjustments.<br>C: Instructed not to change their activity level during the eight weeks. | O: Inclinometry of pelvis tilt in standing defined as the angle between an ASIS/PSIS line and the horizontal plane.<br>*Theta*, an index of lumbar lordosis calculated from the length and depth of the lordosis, measured using a flexible ruler in standing position.<br>Abdominal muscle strength (Kendall double leg lowering test). | Analysis of covariance in the experimental group vs. controls showed an increased abdominal muscle strength (p = 0.001), but no relationship to a mean reduction of 0.5° (pre 8.7 ° vs. post 8.2°) anterior pelvic tilt was found (p = 0.17). | 12 subjects were replaced during the intervention period |
| Barbosa et al, 2013[28] | Intervention study without control | *n* = 7; F/M: NA<br>Age: 18–35 years | Anterior pelvic tilt and LBP without radiculopathy | Eight weeks (3 sessions per week). HVLA thrust applied to the SIJ. At MVC 12%, isotonic eccentric contractions for knee flexion and concentric contractions of knee flexion were applied. The number of repetitions and series varied in each session. | P: VAS<br>O: Digital photogrammetry in standing of pelvis tilt defined as the angle between an ASIS/PSIS line and the horizontal plane. | P: Baseline 5.83 ± 1.59 cm and final assessments 1.29 ± 0.58 cm (p = 0.009).<br>O: Baseline 20.38 ± 5.70 degrees and final assessment 14.63 ± 2.17 degrees. Change of 5.8 degrees (p = 0.009). | No |
| Lee et al, 2014[31] | Intervention study without control | n = 16 females<br>Mean age ± *SD* = 23.63 ± 3.18 years | Habitually wearing high-heeled shoes and having pain in both SIJs during ASLR | The immediate and 24-hour follow-up effect of an application of posterior pelvic tilt taping (PPTT) using kinesiology tape aiming at decreasing anterior pelvic tilt | P: A six-point scale for disability on the ASLR test ranging from 0 (not difficult at all) to 5 (unable to perform).<br>O: Inclinometry of pelvis tilt in standing defined as the angle between an ASIS/PSIS line and the horizontal plane. | After one day of PPTT all results (p < 0.001)<br>P: ASLR scores (mean ± *SD*)**<br>Dominant side 3.00 ± 1.10 to 1.38 ± 1.08<br>Non-dominant side 2.75 ± 1.18 to 1.25 ± 1.13.<br>O: Pelvic tilt (mean° ± *SD*)**<br>Dominant side 11.97 ± 2.81 to 7.16 ± 2.87. Change of 4.8 degrees.<br>Non-dominant side 12.68 ± 2.76 to 7.25 ± 2.45. Change of 5.4 degrees. | No |

*Note*. Studies are presented methodologically with RCTs before non-RCTs and publication year.
LBP, low back pain; NA, not applicable; HVLA, high velocity, low amplitude; SIJ, sacroiliac joint; MVC, maximum isometric voluntary contractions; ASIS, anterior superior iliac spine; PSIS, posterior superior iliac spine; VAS, visual analogue scale; RCT, randomized controlled trial; ASLR, active straight leg raise test; SIJ, sacroiliac joint.
*n (number of participants), F/M (female/male).
**Criteria for dominant/non-dominant side are not defined. All patients are described as right-side dominant.

test in supine position. The eight-week intervention consisted primarily of abdominal strengthening exercises supplemented with stretching exercises. Pelvic tilt was measured using inclinometry.

Regarding the intervention studies without control: Barbosa et al[28] included patients with non-pre-specified degree of anterior pelvic tilt (mean 20.4 degrees) in combination with low back pain without radiculopathy (*n* = 7, gender ratio not reported, age range 18–35 years). The eight-week intervention consisted of high-velocity low-amplitude (HVLA) manipulative thrust applied to the sacroiliac joint, followed by quadriceps eccentric and

**Table 2.** Cochrane Collaboration tool to assess risk of bias for randomized controlled trials

| Authors, year | Risk of bias within each domain | | | | | | | Overall risk of bias across studies |
|---|---|---|---|---|---|---|---|---|
| | **Selection bias** Random sequence generation | **Selection bias** Allocation concealment | **Reporting bias** Selective reporting | **Other bias** Other sources of bias | **Performance bias** Blinding (participants and personnel) | **Detection bias** Blinding (outcome assessment) | **Attrition bias** Incomplete outcome data | |
| Cottingham et al, 1988[30] | Unclear | Unclear | Unclear | High | High | High | Low | High |
| Levine et al, 1997[29] | Unclear | Unclear | Unclear | High | High | Unclear | High | |

Judgement: Bias is assessed as a judgment (high, low, or unclear) for individual elements from five domains (selection, performance, attrition, reporting, and other).
Assessment of risk of bias (version 5.1.0):
*(Within a study) Low risk of bias:* Low risk of bias for all key domains
*Unclear risk of bias:* Unclear risk of bias for one or more key domains
*High risk of bias:* High risk of bias for one or more key domains
*(Across studies) Low risk of bias:* Most information is from studies at low risk of bias
*Unclear risk of bias:* Most information is from studies at low or unclear risk of bias
*High risk of bias:* The proportion of information from studies at high risk of bias is sufficient to affect the interpretation of results

**Table 3.** The risk of bias in non-randomized studies of interventions (ROBINS-I) assessment tool

| Authors, year | Risk of bias within each domain | | | | | | | Overall risk of bias across domains | Overall risk of bias across studies |
|---|---|---|---|---|---|---|---|---|---|
| | **Confounding** | **Participant selection** | **Intervention classification** | **Departure from intended interventions** | **Missing data** | **Measurement of outcomes** | **Selection of reported results** | | |
| Barbosa et al, 2013[28] | Critical | Critical | Serious | Moderate | Moderate | Critical | Moderate | Critical | High |
| Lee et al, 2014[31] | Critical | Serious | Serious | Moderate | Moderate | Serious | Moderate | Critical | |

Judgement (within a study): *Low risk of bias* (comparable to a well performed randomized controlled trial: RCT), *Moderate risk of bias* (sound, but not comparable to a well performed RCT), *Serious risk of bias* (important problems), *Critical risk of bias* (too problematic to provide useful evidence), *No information.*
*(Across studies) Low risk of bias:* Most information is from studies at low risk of bias
*Unclear risk of bias:* Most information is from studies at low or unclear risk of bias
*High risk of bias:* The proportion of information from studies at high risk of bias is sufficient to affect the interpretation of results

hamstring concentric contractions. The effect was assessed using 'VAS-pain intensity' and digital photogrammetry analysis where the pelvic tilt angle was found between two digitally drawn lines.

Lee et al[31] included patients having an anterior pelvic tilt at baseline between 11 and 13 degrees, habitually wearing high-heeled shoes in combination with bilateral sacroiliac joint pain (16 females, mean age 23.6 years). Posterior pelvic tilt taping was applied and the effect on symptoms and pelvic tilt was assessed immediately and after one day using a '6-point scale for disability' and inclinometry measuring pelvic tilt.

### *Risk of bias within studies*

Risk of bias within the two RCTs was rated as *High* (Table 2). Regarding both RCTs, no description of randomization or allocation concealment methods were presented, no reporting of a priori protocols and no blinding of participants or therapists. In the study from Cottingham et al,[30] the assessor was not blinded whereas Levine et al[29] used two assessors independent from the authors. However, assessor blinding procedure was not described. Furthermore, in the study by Levine et al[29] 12 out of 20 subjects were replaced during the eight-week intervention due to lack of adherence to the training protocol. No baseline characteristics or analysis of the excluded subjects was provided.

Risk of bias within the two intervention studies without control[28,31] was rated as *High* (Table 3). Without a control group, the studies are at high risk of bias regardless of other weaknesses or strengths.[26]

### *Results of individual studies*

Regarding the two RCTs: Cottingham et al[30] demonstrated, on 16 healthy non-symptomatic males with pelvic anterior pelvic tilt exceeding nine degrees, that 45 minutes of Rolfing soft tissue manipulation/pelvic mobilization resulted in significant between-group effects. The test group had an immediate and 24-hour mean decrease of anterior pelvic tilt of 1.7 ° and 1.4 ° ($p < 0.01$), respectively. The control group did not show significant differences of pelvic tilt.

Levine et al[29] demonstrated that an eight-week abdominal strengthening dominated programme on 20 healthy non-symptomatic subjects significantly ($p = 0.001$) increased the abdominal muscle strength compared to the control group, but no relationship to anterior pelvic tilt was found.

Regarding the two intervention studies without control, Barbosa et al[28] showed, over an eight-week intervention via HVLA thrusts applied to the sacroiliac joints in combination with muscle activation for improving pelvic stabilization on seven LBP patients, a significant 4.5 cm ($p = 0.009$) reduction of low back pain on a 10 cm VAS and 5.8 degrees ($p = 0.009$) of anterior pelvic tilt. Lee et al[31] demonstrated that a one-day application of posterior pelvic tilt taping (PPTT) on 16 women, habitually wearing high-heeled shoes and having pain in both sacroiliac joints during active straight leg raise (ASLR) test, significantly decreased perceived disability in the ASLR test and averagely reduced anterior pelvic tilt with 5.1 degrees ($p < 0.001$), during and one day after PPTT application.

*Synthesis of results*

Pelvic tilt was, in all four included studies, measured as the angle between the ASIS/PSIS line and the horizontal plane. In one study digital photogrammetry was used,[28] and for the rest, hand-held inclinometry.[29–31]

The two studies intervening on symptomatic patients demonstrated a significant reduction in LBP[28] and sacroiliac joint pain during the ASLR test[31] in combination with a significant reduction in anterior pelvic tilt. The type and length of treatment were not comparable as one of the studies[28] used HVLA thrusts applied to the sacroiliac joint in combination with muscle activation for eight weeks, and the other study used a one-day application of posterior pelvic kinesiology taping.[31] Neither of the two studies used a control group.

Three of the four included studies demonstrated a significant reduction in anterior pelvic tilt.[28,30,31] Common to the three studies with a positive outcome on pelvic tilt, was that subjects presented a more pronounced excessive anterior pelvic tilt at baseline (12.0–20.4°), leaving more room for improvement, than the study not observing reduced pelvic tilt (8.7°) following the intervention.[29] The significant reductions in anterior pelvic tilt were 1.7°,[30] 5.1 °,[31] and 5.8°.[28]

*Risk of bias across studies*

The overall risk of bias across the two randomized controlled trials[29,30] is assessed as *High* (Table 2), due to missing description of randomization, allocation concealment and blinding of participants, therapists, and assessors. Therefore, the information from the studies is at high risk of affecting the interpretation of the results.

The overall risk of bias across domains for the two non-randomized studies is presented in Table 3. Barbosa et al[28] was assessed as having *Critical risk of bias*, indicating that the study is methodologically problematic and cannot provide useful evidence. Lee et al[31] was assessed as having *Serious risk of bias*, indicating important methodological problems resulting in a limited level of evidence.

Inspired by the GRADE approach,[27] the overall quality of evidence was due to differences in populations and types of interventions downgraded due to *Very serious 'Risk of bias'* with *Very serious 'Inconsistency' in the reported results*. Furthermore, as no evidence for which type of intervention is effective for a specific group of patients was presented, *Very serious 'Indirectness'* was observed. Finally, the category *'Impression'* was determined as *Very serious* as no outcomes were reported with confidence intervals, change standard deviations, and small sample sizes were used. Thus, the overall certainty of evidence on the effect of non-surgical treatment in reducing excessive anterior pelvic tilt in adults was graded as *Very low*.

## Discussion

The present systematic review investigated the effect of non-surgical treatment in reducing anterior pelvic tilt and potential related clinical symptoms in adults, and evaluated the risk of bias and the certainty of evidence. Of 5047 citations, four studies were included: two RCTs ($n = 72$) and two trials without a control group ($n = 23$). All four types of intervention were different. Three studies demonstrated a statistically significant reduction in anterior pelvic tilt. The two studies without a control group intervening on symptomatic subjects reported a statistically significant reduction in pain and disability. The overall certainty of evidence was assessed as very low.

*Strengths and limitations*

The strengths of this systematic review include a PROSPERO study protocol that was made publicly available a priori ensuring methodological transparency, a systematic search to maximize identification of all relevant published studies and usage of recognized quality assessment tools.[25–27] This systematic review is the first to investigate the effect of non-surgical treatment in reducing anterior pelvic tilt and potential related clinical symptoms in adults, therefore making it difficult to compare the results. A previous narrative review by Hrysomallis and Goodman referred to mechanistic objective outcomes only (e.g. muscle strength and length) and was not restricted to the pelvic area only.[32] The authors found it questionable whether resistance training would produce an adaptive shortening of a muscle and elicit postural changes, even if potential tight agonist muscles were lengthened by stretching. However, the narrative review was limited by its lack of systematic literature search and neither of the two RCTs included in the present systematic review were included in the review from Hrysomallis and Goodman. Furthermore, this systematic review included patient-reported outcomes too, as they are important in understanding the relevance and full potential clinical benefits from the patient's point of view. We did not investigate other postural relationships that potentially can affect pelvic tilt including spinal alignment and deformity, leg alignment and deformity, and leg length differences. This review focused on the isolated effect of non-surgical treatment in reducing anterior pelvic tilt. This review is limited by the paucity of studies in this research area and thus a lack of a meta-analysis, and the heterogeneity in study methods, populations and types of intervention.

### *Clinical relevance*

Spinopelvic sagittal balance is described as an interrelation of muscle function,[22,33] and spinal and pelvic morphology[9,34] and variations in sagittal posture are tolerated to some extent.[9,35] Despite a suggested interrelationship in the literature, there is no causal evidence that excessive anterior pelvic tilt leads to pain, loss of function or reduced quality of life. The relationship between mechanical factors and incidence of LBP was assessed in 600 individuals and no association between anterior pelvic tilt and LBP was found.[36] This systematic review found a very limited number ($n$ = 4) of eligible intervention studies. A reason could be that excessive anterior pelvic tilt is not well defined and/or directly causing symptoms.

Levine et al[29] found no relationship between anterior pelvic tilt in standing and an increase in abdominal muscle strength, which is consistent with previous studies on asymptomatic subjects[37–39] as well as patients with chronic low back pain.[40] The cutoff level defining excessive anterior pelvic tilt was set at eight degrees in the present review. It is therefore questionable whether the baseline value of 8.7 degrees of anterior pelvic tilt, in the study by Levine et al, is clinically relevant to attempt reducing by strengthening the abdominal muscles. It is suggested that attention should be given to the complex sensorimotor control system integrating muscle coordination, rather than muscle strength alone, in avoiding excessive anterior pelvic tilt.[41] That theory was successfully investigated in a study[42] on 54 male adolescents (aged 13–17 years, and consequently excluded from the present systematic study due to the low age) with excessive pelvic tilt (> 14°) randomized into three groups (*strength training, strength training and sensorimotor training*, and *non-exercising control*). A significant larger degree of reduction in anterior pelvic tilt in the *strength training and sensorimotor training* group (3.3°+ 2.2°) compared to the *strength training* only group (1.6°+ 1.8°) was observed. Thus, it cannot be excluded that patients suffering from clinical symptoms related to excessive anterior pelvic tilt may benefit from sensorimotor training.

Barbosa et al[28] found a significant reduction in symptoms (LBP) and the largest numeric reduction in anterior pelvic tilt (5.8°, p = 0.009) of the four included studies. However, due to serious risk of bias, the positive results of HVLA thrusts applied to the sacroiliac joints in combination with muscle activation of the thigh could be due to coincidence, be biased or a placebo effect, and should be interpreted with caution. The long-term effect of the two other studies, Cottingham et al[30] and Lee et al,[31] presenting a positive treatment effect, is inconclusive due to a follow-up time of only one day.

### *Clinical perspective and future research*

No evidence supports excessive anterior pelvic tilt as an isolated clinical disorder or pathology, and a valid cutoff point defining excessive anterior pelvic tilt is problematic as the spinopelvic sagittal balance can be individually regulated to maintain a proper posture.[43,44] Consequently, excessive anterior pelvic tilt must be addressed within a specific condition and possibly also on an individual level. Thus, methodologically high-quality interventions targeting specific types of impairments, biomechanically related to, and in combination with, excessive anterior pelvic tilt are warranted. An area for future research could therefore be to investigate the effect of a non-surgical treatment aiming to reduce excessive anterior pelvic tilt and symptoms in patients with FAI caused by acetabular retroversion, as a potential alternative to surgery. The use of patient-reported outcome measures in combination with objective measures of pelvic tilt is important to differentiate whether the effect of interventions is related to a reduction of pelvic tilt (change of posture) per se, or to mechanical/mechanistic alterations.

## Conclusions

Due to limited literature and in general low-quality designs no overall evidence for the effect of non-surgical treatment in reducing excessive anterior pelvic tilt and potentially related symptoms was found. The absence of evidence suggests that high-quality interventions targeting non-surgical treatment as an alternative to invasive surgery in reducing anterior pelvic tilt and/or related symptoms are warranted.

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**Appendix 1.** Search strategy for MEDLINE

*Search strings*

1. (spinopelvic OR spino-pelvic OR pelvic OR pelvis [MeSH]) AND (tilt OR tilts OR anteversion OR anteflexion)
2. (Posture [MeSH] OR postures OR postural) AND (alignment OR realigning OR realignment OR realignments OR malalignment OR malalignments OR mal-alignment OR mal-alignments)

## 14.2. Paper II. Radiographic case-control study

# Increased anterior pelvic tilt in patients with acetabular retroversion compared to the general population: A radiographic and prevalence study

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## Abstract

### Background and purpose

Acetabular retroversion may cause femoral head over-coverage, which is associated with femoroacetabular impingement syndrome (FAIS). Anterior pelvic tilt increases femoral head coverage and thus enhances the risk of FAIS. The purpose of this study was to investigate whether patients with symptomatic and radiographically verified acetabular retroversion demonstrated increased anterior pelvic tilt, compared to a control group, and furthermore to evaluate the prevalence of acetabular retroversion in the general population.

### Patients and methods

We assessed 111 patients with acetabular retroversion and 132 matched controls, representing the general population. Pelvic tilt was assessed by the *sacrococcygeal joint–symphysis distance* and *pelvic-tilt-ratio*. Acetabular retroversion was defined as positive cross-over sign (COS) and posterior wall sign (PWS). A nonparametric regression model was used to test potential between-group differences in median pelvic tilt. The prevalence was the ratio of subjects, and hips with acetabular retroversion, respectively.

**Results**

Compared to the control group, the patient group had significantly larger anterior pelvic tilt. In the general population there was a prevalence of acetabular retroversion of 24% on subject-level (19 females [59%], 13 males [41%]) and 18% of all hips.

**Interpretation**

We found that patients with symptomatic acetabular retroversion have increased anterior pelvic tilt compared to the general population. This should be diagnosed and considered when treating patients with acetabular retroversion, as it may influence indication for surgery. Radiographic acetabular retroversion was highly prevalent in the general population which has to be taken into considerations when diagnosing patients with hip related pain.

## Introduction

Genuine acetabular retroversion is a variant of hip dysplasia (Reynolds et al., 1999, Siebenrock et al., 2003b), defined as a radiological sign when the cranial opening of the acetabulum is posterior. The combined presence of the cross-over sign (COS) and the deficient posterior wall sign (PWS) – has been described for identification of genuine acetabular retroversion (Reynolds et al., 1999). Acetabular retroversion may cause femoroacetabular impingement syndrome (FAIS) due to an over-coverage of the femoral head (Reynolds et al., 1999). FAIS is associated with pain, reduced function and quality of life, as well as the early development of hip osteoarthritis (Ganz et al., 2003). Patients with acetabular retroversion may have increased anterior pelvic tilt (i.e., inclination), which exacerbates femoral head coverage and hence increases the frequency of radiographic signs for retroversion (i.e. functional acetabular retroversion) (Dandachli et al., 2013, Ross et al., 2014). Consequently, anterior pelvic tilt combined with acetabular retroversion enhances the risk of FAIS and related symptoms (Henebry and Gaskill, 2013, Ross et al., 2014). Anterior pelvic tilt is preferentially evaluated on sagittal plane radiographs, but because of the high radiation dose, it is frequently assessed on anteroposterior radiographs (Tannast et al., 2006, Schwarz et al., 2018). Most patients with symptomatic acetabular retroversion are treated non-surgically, but a few undergo an anteverting periacetabular osteotomy (PAO), with the aim of reorientation of the acetabulum and reduction of impingement symptoms (Siebenrock et al., 2014). However, it is important to clarify if patients with symptomatic acetabular retroversion demonstrate excessive anterior pelvic tilt, as it potentially contributes to the overall symptoms, and may be treated non-surgically.

The purpose of this study was to investigate whether patients with symptomatic and radiographically verified acetabular retroversion demonstrated increased anterior pelvic tilt, compared to a control group, and furthermore to evaluate the prevalence of acetabular retroversion in the general population.

## Patients and methods

### *Study design*

This case-control study was approved by the Danish Patient Safety Authority (3-3013-1660/1) and the executive board of the Copenhagen City Heart Study (HEH-2015-045). The STROBE Statement (von Elm et al., 2008) was used as reporting guidelines.

### *Setting and participants*

Inclusion criteria for the study group. We identified and included patients with symptomatic acetabular retroversion prior to PAO, between 20 and 40 years old, who underwent preoperative anteroposterior pelvic radiographs in standing position showing radiological signs of retroversion (COS+PWS), which were verified using computed tomography scanning (CT-scan). The patients underwent PAO between January 2007 and January 2018 at Odense University Hospital, Denmark. They had symptoms for more than 3 months, were diagnosed with symptoms of FAIS during physical examination, and non-surgical treatment was deemed unsuccessful (Reynolds et al., 1999).

Inclusion criteria for the control group. Controls were randomly selected from the general population among 4,151 participants from the longitudinal health survey *The Copenhagen City Heart Study III* (CCHS-III) (Schnohr P, 2001) recorded from 1991 to 1994. Controls were matched – 2 (controls):1 (patient) – by an independent employee (ALM) according to 5-year age intervals (20–25; 26–30; 31–35; 36–40 years) and sex. Anteroposterior pelvic radiographs of the controls in standing position were assessed. Exclusion criteria were the same as for the patients (see below).

In case of exclusion, a matched replacement was randomly found. The following exclusion criteria were applied for both groups: Radiographic sign of hip osteoarthritis (<2 mm joint space), previous lumbar, pelvic or hip-related surgery, childhood hip pathology (slipped capital femoral epiphysis, Perthes disease), or Tönnis foramen obturator index (FOI) (Tonnis, 1976) (maximum horizontal width of the right obturator foramen divided by the left) exceeding the limit values of 0.7–1.8 in pelvic rotation. Moreover, patients were excluded if it was not possible to identify radiographic landmarks and measure pelvic tilt.

### *Radiographic procedure*

In both groups, the anteroposterior radiographs were recorded in the standing position with the X-ray beam centered approximately two fingerbreadths over the symphysis in the vertical midline. Patients stood with 15 degrees of bilateral internal rotation of the hips, and the controls with the feet pointing straight forward. The tube-to-film distance was 115 cm in the patient group and 120 cm in the control group. Radiographs were assessed digitally using TraumaCad® software on a high-resolution imaging monitor for the study group, and conventionally on printed film using a protractor and ruler, for the control group.

### *Outcome measures*

Radiographs were assessed for pelvic tilt (by two methods) and signs of acetabular retroversion. Pelvic tilt – was assessed using two methods as we have experienced it may be impossible to identify the sacrococcygeal joint by the first method, which may result in several exclusions (Jackson et al., 2016). Method 1: The vertical distance (in mm) was measured as the *sacrococcygeal joint–symphysis distance* (Tannast et al., 2006) (Figure 1A). Method 2: the *pelvic-tilt-ratio* was calculated as the ratio between the central height of the obturator foramina and the height of the lesser pelvis (Schwarz et al., 2018) (Figure 1B).
Acetabular retroversion – was defined as the combined presence of COS and PWS (COS+PWS) (Reynolds et al., 1999) (Figure 1C). The ischial spine sign (ISS) is also related to acetabular retroversion, and suggested as a radiographic sign of an externally rotated hemipelvis (Kalberer et al., 2008) (Figure 1C). The ischial spine, however, is not an anatomically part of the hip joint and thus not related to FAIS, why it is not included in the present study (Kalberer et al., 2008).

Additional radiographic signs potentially related to acetabular retroversion were assessed: lateral center-edge angle (LCEA, >40° is indicative of acetabular retroversion) (Jesse et al., 2013) (Figure 1E) and acetabular index angle (AIA, <0° is indicative of acetabular retroversion) (Jesse et al., 2013) (Figure 1F). The COS-ratio was calculated as the ratio of the length of the anterior acetabular wall lying anterior to the posterior acetabular wall in the cranial portion of the joint to the entire length of the acetabulum (Nepple et al., 2013) (Figure 1D). The COS-ratio was assessed for the patient group only, as previous drawings on the screen-film radiographs made accurate measure impossible.

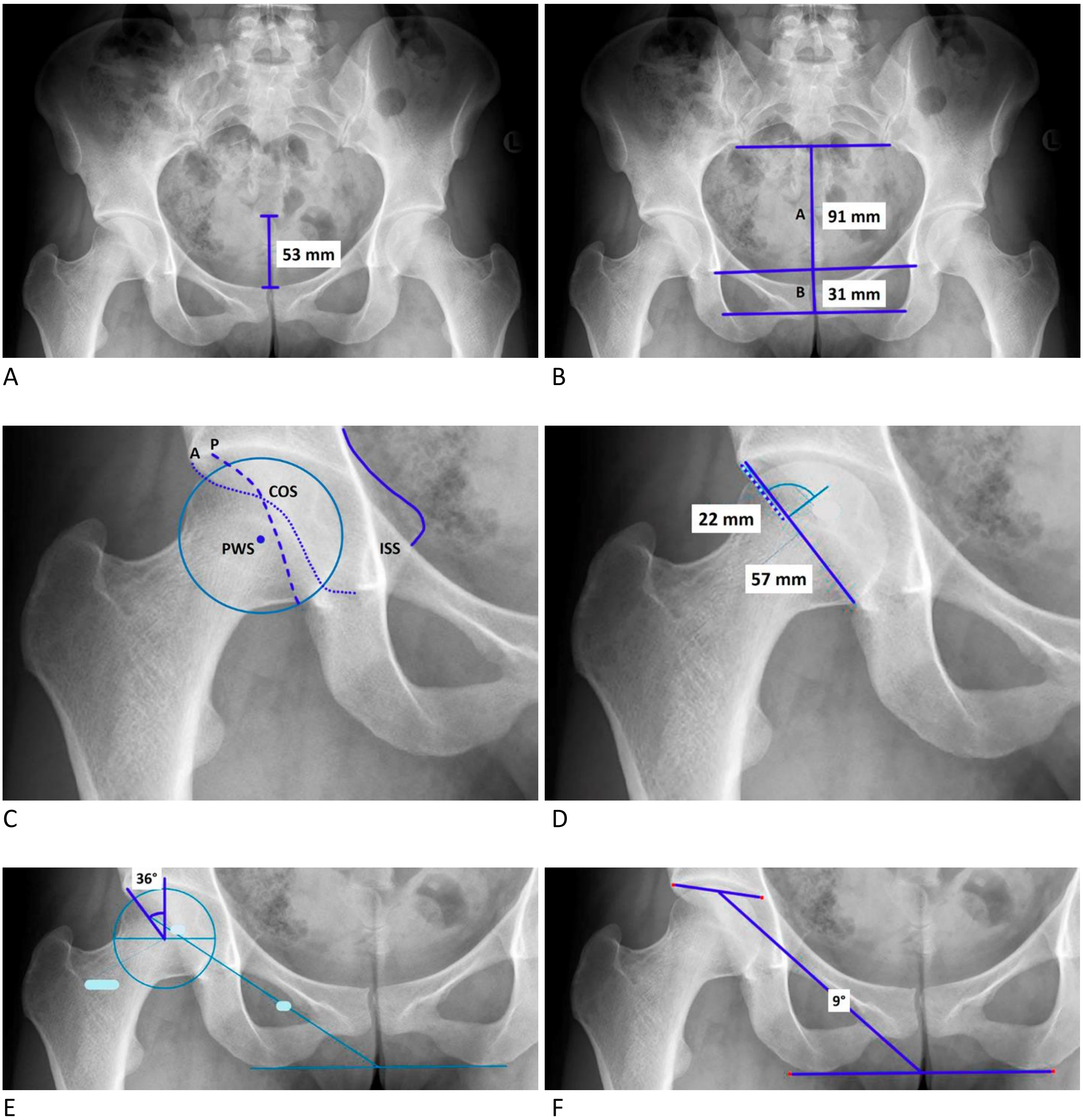


**Figure 1. Anteroposterior pelvic radiographs in standing position (A – F)**
**A**, Pelvic tilt assessed by measuring the distance from the sacrococcygeal joint to the upper edge of the symphysis (SC-S is 53 mm on the figure). Increased anterior pelvic tilt results in greater SC-S distance.

**B**, Pelvic tilt assessed by *pelvic tilt ratio* (PTR). Three transversal lines are drawn; 1) between the inferior margins of the sacroiliac joints, and 2) between the superior and 3) inferior borders of the obturator foramina. The PTR is the ratio (B/A) between the central height of the obturator foramina and the height of the lesser pelvis (PTR = (31/91) = 0.34 on the figure). Neutral, anterior, and posterior pelvic tilt is indicated by PTR = 0.5, PTR <0.5, and PTR >0.5, respectively.

**C**, The cross-over sign (COS) appears when the cranial part of the anterior wall of the acetabulum (dotted line A) is crossing the posterior acetabular wall (banded line P). The posterior wall sign (PWS) is present when the posterior wall of the acetabulum is located medial to the center of the femoral head (blue dot). The ischial spine sign (ISS) is present when the ischial spine is visible within the pelvic inlet (all three signs for acetabular retroversion is positive on the figure).

**D**, The cross-over sign ratio (COS-ratio) is measured as the ratio of the length of the anterior acetabular wall lying anterior to the posterior acetabular wall in the superior portion of the joint (dotted line, 22 mm) to the entire length of the acetabulum (solid line, 57 mm). (The COS-ratio is 0.39 on the figure). COS-ratios >33% to 50% indicate relatively severe retroversion (Nepple et al., 2013).

**E**, The lateral center-edge angle of Wiberg (LCEA) is measured between two lines drawn from the center of the femoral head, one running vertically perpendicular to a line connecting the inferior ischial tuberosities, and the other to the edge of lateral acetabular sourcil. (LCEA is 36° on the figure). Acetabular over-coverage is characterized by an LCEA >40° (Jesse et al., 2013).

**F**, The acetabular index angle of Tönnis (AIA) is measured between a line connecting the inferior ischial tuberosities and a line connecting the lateral and medial edges of the acetabular sourcil. (AIA is 9° on the figure). Acetabular over-coverage is characterized by an AIA <0° (Jesse et al., 2013).

### *Quality assessment of radiographs*

All outcome measures were evaluated by the first author and assessed bilaterally in both groups, regardless of unilateral or bilateral symptoms. Prior to assessments, interrater reliability analysis was performed on 50 randomly selected digital radiographs (50 pelvises / 100 hips) by an experienced radiologist (TT) and the first author (AFB). Cohen's kappa coefficient (*k*) was calculated for the categorical outcome measures (COS = 0.64, PWS = 0.89, ISS = 0.91), and the intraclass correlation coefficient (two-way random effects model for absolute agreement) ($ICC_{2.1}$) was calculated for the continuous outcome measures (*sacrococcygeal joint–symphysis distance* = 0.97, *pelvic-tilt-ratio* = 0.92, LCEA = 0.91, AIA = 0.96, COS-ratio = 0.95).

Image quality was assessed in all the included radiographs to ensure complete data for equal between-group comparison. Subjects with radiographs where landmarks of pelvic tilt (*sacrococcygeal joint–symphysis distance* or *pelvic-tilt-ratio*), and hips where landmarks of acetabular retroversion (COS or PWS) could not be identified, respectively, were excluded before final assessments.

### *Statistics*

Data were assessed for Gaussian distribution by visual inspection of histograms and QQ-plots, and the Shapiro–Wilk test. Accordingly, nonparametric descriptive statistics were used to test potential between-group differences using the two-sample Wilcoxon rank-sum test and the Chi-square test on continuous and dichotomous data, respectively.

A nonparametric regression model, adjusted for age, BMI, and sex, was used to test potential between-group differences in median pelvic tilt supplied with 95% confidence intervals (95% CI). Age and BMI are potentially related to pelvic tilt (Been and Kalichman, 2014), and the *sacrococcygeal joint–symphysis distance* is reported greater in females compared to males at the same degree of pelvic inclination (Siebenrock et al., 2003a).

A p-value ≤0.05 was considered significant. STATA/IC 16 (StataCorp. LP, College Station, TX, USA) was used for the statistical analysis.

## Results

In the study group, 151 patients with acetabular retroversion selected for PAO were considered for analysis (Figure 2). A total of 111 patients (111 pelvises / 222 hips) were included. Matching controls was successful for three out of four age groups. However, for the youngest age group (20–25 years), 75 females and 15 males were missing for complete matching. Thus, a total of 132 controls (132 pelvises / 264 hips) were included (Table 1).

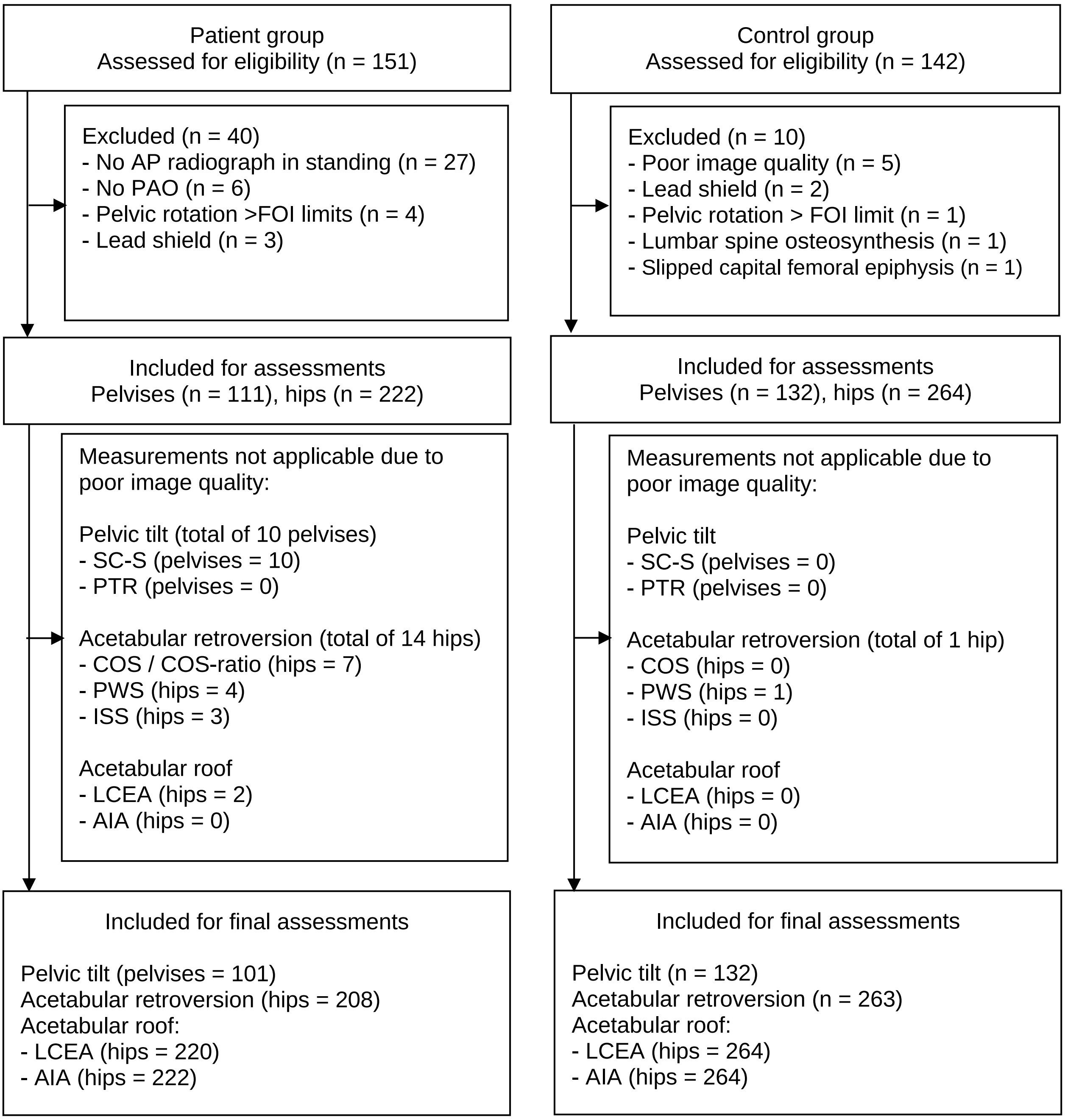


**Figure 2. Flow diagram for eligibility assessment and inclusion of participants**

**Table 1. Between-group differences in participant characteristics and matching**

| | Patients | General population | Δ group [a] | p-value |
|---|---|---|---|---|
| Characteristics | | | | |
| Sex, n (F/M) (%) | 111 (83/28) (75/25) | 132 (91/41) (69/31) | | 0.32 [b] |
| Age, years, Median (IQR) | 24 (22–29) | 29 (25–35) | -5 | <0.01 [c] |
| BMI, kg/m$^2$, Median (IQR) | 24 (21–27) | 23 (21–24) | 1 | 0.01 [c] |
| SC-S (mm), females, Median (IQR) | 58 (49–65) | 42 (31–52) | 16 | <0.001 [c] |
| SC-S (mm), males, Median (IQR) | 36 (30–50) | 22 (2–31) | 14 | <0.001 [c] |
| PTR, females, Median (IQR) | 0.31 (0.26–0.34) | 0.39 (0.33–0.48) | -0.08 | <0.001 [c] |
| PTR, males, Median (IQR) | 0.36 (0.30–0.43) | 0.47 (0.40–0.61) | -0.11 | <0.001 [c] |
| Matching | | | | |
| 20-25 yr. n (F/M) | 64 (49/15) | 38 (23/15) [d] | | 0.09 [b] |
| 26-30 yr. n (F/M) | 21 (12/9) | 42 (24/18) | | |
| 31-35 yr. n (F/M) | 12 (10/2) | 24 (20/4) | | |
| 36-40 yr. n (F/M) | 14 (12/2) | 28 (24/4) | | |

[a] Median difference, [b] Chi-square test, [c] Wilcoxon rank-sum test, [d] Incomplete matching 2 (controls):1 (patient), no statistical difference in the distribution of sex (p = 0.09).
Δ: difference, n: numbers, F/M: females/males, %: percent, IQR: interquartile range, BMI: body mass index, SC-S: vertical distance between the sacrococcygeal joint and the upper edge of the symphysis, mm: millimeters, PTR: pelvic tilt ratio.

### *Included patients*

Pelvic tilt assessment. Subjects with radiographs where landmarks of pelvic tilt (*sacrococcygeal joint–symphysis distance* or *pelvic-tilt-ratio*) could not be identified, (n = 10, [9%] for the study group and none for the control group), were excluded before final assessment. Hence, 101 pelvises and 132 pelvises remained for analysis for the study and control groups, respectively (Figure 2).

Acetabular retroversion assessment. Hips with radiographs where landmarks of acetabular retroversion (COS or PWS), could not be identified, (n = 14, [6%] for the study group and (n = 1, [0.4%]) for the control group, were excluded before final assessment. Hence, 208 hips and 263 hips remained for analysis for the study and control groups, respectively (Figure 2).

### *Pelvic tilt*

The study group had significantly larger median anterior pelvic tilt of 14.3 mm (95% CI: 8.9–19.6) in the *sacrococcygeal joint–symphysis distance* and -0.08 (95% CI: -0.11– -0.04) in *pelvic-tilt-ratio* compared to the control group (Table 2.). Sex was the only independent variable associated with both outcomes on pelvic tilt in the fitted regression model, showing that females had, compared to males, increased *sacrococcygeal joint–symphysis distance* of 21.6 mm and decreased *pelvic-tilt-ratio* of 0.06, p <0.01).

**Table 2. Between-group differences in pelvic tilt measured by two methods.**

| | Patients n = 101, F/M (74/27) Median (IQR) | General population n = 132, F/M (91/41) Median (IQR) | Unadjusted median difference [a] (95% CI) | Adjusted median difference [b] (95% CI) |
|---|---|---|---|---|
| Methods: | | | | |
| 1) SC-S (mm) | 54 (39–65) | 35 (20.5–49) | 19 (13.2–24.8) * | 14.3 (8.9–19.6) * |
| 2) PTR | 0.32 (0.26–0.35) | 0.41 (0.34–0.52) | -0.09 (-0.12– -0.05) * | -0.08 (-0.11– -0.04) * |

[a] Nonparametric regression model, [b] Nonparametric regression model adjusted for age, BMI, and sex.
* P <0.001, n: numbers, F/M: females/males, IQR: interquartile range, 95% CI: 95 percent confidence interval, mm: millimeters, SC-S: vertical distance between the sacrococcygeal joint and the upper edge of the symphysis, PTR: pelvic tilt ratio.

### *Prevalence of acetabular retroversion*

All 111 patients in the study group had either unilateral or bilateral retroversion of the hip(s). A total of 32 out of 132 controls (24%) (19 females [59%], 13 males [41%]) had acetabular retroversion (unilateral/bilateral: 16/16). The study group had significantly higher prevalence of hips with acetabular retroversion (COS+PWS) (73% vs. 18%, p <0.01) compared to the control group (Table 3).

**Table 3. Between-group differences in radiographic signs of acetabular retroversion**

| | Patients | General population | Δ group | p-value |
|---|---|---|---|---|
| Radiographic signs | | | | |
| Prevalence – hips | n = 208, y/n (yes %) [a] | n = 263, y/n (yes %) [b] | | |
| COS | 198/10 (89) | 84/179 (32) | 57 [c] | <0.01 [d] |
| PWS | 167/41 (80) | 60/203 (23) | 57 [c] | <0.01 [d] |
| ISS | 153/55 (74) | 65/198 (25) | 59 [c] | <0.01 [d] |
| **COS+PWS**, acetabular retroversion | **163/45 (73)** | **48/215 (18)** | 55 [c] | <0.01 [d] |
| COS+PWS+ISS | 132/76 (59) | 36/227 (14) | 45 [c] | <0.01 [d] |
| COS-ratio, Median (IQR) | 0.27 (0.2–0.36) | | | |
| Acetabular retroversion | | | | |
| Prevalence – subjects | n = 111 (100%) (PAO) | n = 32 (24%) (COS+PWS) | | |
| n (unilateral/bilateral) (%) | 79/32 (71/29) | 16/16 (50/50) | | |
| Sex, n (F/M) (%) | 83/28 (75/25) | 19/13 (59/41) | | |
| Acetabular roof | | | | |
| LCEA (°), [n = hips] Median (IQR) | [220], 28.5 (24–34) | [264], 30 (25–34) | -1.5 [e] | 0.14 [f] |
| AIA (°), [n = hips] Median (IQR) | [222], 4 (1–8) | [264], 5 (0–8) | -1 [e] | 0.85 [f] |

[a] 14 hips were removed due to poor image quality, [b] One hip was removed due to poor image quality, [c] Percentage points difference, [d] Chi-square test, [e] Median difference, [f] Wilcoxon rank-sum test.
Δ: difference, n: numbers, y/n: yes/no, %: percent, COS: cross-over sign, PWS: posterior wall sign, ISS: ischial spine sign, IQR: interquartile range, PAO: diagnosed with acetabular retroversion and operated with periacetabular osteotomy, F/M: females/males, LCEA: lateral center-edge angle, AIA: acetabular index angle, °: degrees.

## Discussion

This is the first study reporting on pelvic tilt in patients with pincer-type impingement and on prevalence of acetabular retroversion in the general population.

We showed that patients with symptomatic acetabular retroversion have increased anterior pelvic tilt compared to the general population. The general population had a prevalence of acetabular retroversion of 24% on subject-level and 18% on hips.

### *Pelvic tilt*

Our study showed increased anterior pelvic tilt in patients with acetabular retroversion compared to the general population. The results from our study on the *sacrococcygeal joint–symphysis distance* in the study group was larger compared to what was previously reported in patients evaluated for various types of FAIS (Jackson et al., 2016, Pullen et al., 2014). This may be explained by the selection of our patients, who were included due to their need for the surgical correction of verified acetabular retroversion, which has not been previously reported in the literature. The results from our study on the *sacrococcygeal joint–symphysis distance* in the control group (median value of 42 mm in women and 22 in men) were slightly smaller but comparable to what was previously reported by Siebenrock et al (Siebenrock et al., 2003a) (mean value of 47 mm in women and 32 in men). The difference may be due to the radiographs taken in supine position in contrast to our study, which tends to increase anterior pelvic tilt.

In lateral radiographs, normal pelvic tilt/inclination is 60–65° and equal across the sexes (Siebenrock et al., 2003a) measured as the angle between a horizontal line and a line connecting the upper border of the symphysis with the sacral promontory. In anteroposterior radiographs, Siebenrock et al reported females having an increased mean *sacrococcygeal joint–symphysis distance* of 15 mm (47 mm in women minus 32 mm in males), compared to males at the same level of inclination, due to gender wise differences in pelvis morphology (Siebenrock et al., 2003a). This is comparable with our finding of larger median *sacrococcygeal joint–symphysis distances* in females of 22 mm, and 20 mm in the study group and the control group, respectively. However, as we do not have lateral radiographs, it is inconclusive whether there is a difference between the sexes in pelvic inclination in the current study.

### *Prevalence of acetabular retroversion*

The prevalence of hips with acetabular retroversion in the study group was 100% on patient level but 73% on hips as not all patients had bilateral signs of retroversion. For the first time a randomly population-based prevalence of hips with acetabular retroversion was evaluated in the general population. We found in the general population that hips with radiographic signs of acetabular retroversion were highly prevalent with 24% on subject-level and 18% on hips. In comparison, a lower prevalence of 4–7% (Ezoe et al., 2006, Werner et al., 2010) hips with acetabular retroversion in non-orthopaedic patients was reported from anteroposterior radiographs in supine position, with pelvises exhibiting excessive anterior pelvic tilt excluded (Siebenrock et al., 2003a). Thus, our results indicate that radiographic signs of acetabular retroversion are not uncommon in the general population. Due to the current retrospective design, it is unknown if any controls had hip-related symptoms related to acetabular retroversion and the degree of anterior pelvic tilt.

### *Strength and limitations*

We assessed radiographs taken in the standing position, which is considered more clinically relevant compared with the supine position, due to a more natural, functional, and less anterior tilted pelvic position (Jackson et al., 2016). The control group was randomly selected from the general population and thereby contributing to the understanding of acetabular retroversion in a patient-based context. The *sacrococcygeal joint–symphysis distance* is reported as having the strongest positive correlation of six different parameters for both sexes ($r \approx 0.6$, $p < 0.001$) to true pelvic tilt (sagittal reference standard) (Tannast et al., 2006). However, measuring the *sacrococcygeal joint–symphysis distance* may be difficult due to overlying *bowel* obscuring more posterior structures. Thus, we also used the method suggested by Schwarz et al. (Schwarz et al., 2018), who proposed that *pelvic-tilt-ratio* obtained from anteroposterior radiographs may be more precise for assessing pelvic tilt than a single distance measure such as the *sacrococcygeal joint–symphysis distance.* By using *pelvic-tilt-ratio*, we were able to measure pelvic tilt in all patients, but only 91% (n = 10, 9% excluded) using *sacrococcygeal joint–symphysis distance* (Figure 2). *Pelvic-tilt-ratio* is considered a valid estimate of true sagittal pelvic tilt when calculating the *anterior pelvic plane angle* by the provided software (Schwarz et al., 2018).

The present study has some limitations. We were not able to perfectly match the study group to the control group. However, this was adjusted for in the statistical analysis. We used different types of radiographs and measurement tools for digital and analog radiographs for the patient group and control group, respectively. There is no reason to believe that the different types made any systematic bias in outcome (Lampignano and Kendrick, 2017). Additionally, there were small between-group differences for the internal rotation of the hips and tube-to-film distance. However, the measurements in the present study were solely made on the pelvis; apart from the LCEA, which is not influenced by 15° bilateral rotation of the femoral head. Thus, measurement bias due to this reason is highly unlikely. Due to poor image quality, the interrater reliability analysis of COS prior to the final assessments was only *substantial* ($k$ = 0.64). This lead to further improvements in using the TraumaCad® software after which there was agreement between the two raters, in the assessment of COS, on images where there previously had been disagreement. No reliability assessment was conducted on the control group radiographs. However, we assume that the reliability was sustainable as measures made digitally and analogically have shown to be comparable (Eklund et al., 2004). Supporting this assumption, we found that interrater reliability coefficients on the patient group were *substantial* to *almost perfect*. Furthermore, fewer analog radiographs were excluded for the control group because of poor image quality than for the digital radiographs in the patient group.

## Conclusions

We found that patients with symptomatic acetabular retroversion have increased anterior pelvic tilt compared to a control group from the general population. In perspective, this should be considered when treating patients with acetabular retroversion, as it may exacerbate symptoms, and influence indication for surgery. Moreover, we found that radiographic signs of acetabular retroversion were highly prevalent in the general population, which has to be taken into consideration when diagnosing patients with hip related pain.

## Author contributions

AFB, SO, AHL designed the study, AFB collected and analyzed the data, and wrote the draft manuscript, TT ensured the quality of the radiographic analysis, SSH assisted with expertise regarding the control group, AFB, SO, TT, SSH, AHL (all authors) approved the final version of the manuscript before submission.


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## Data sharing

Data will be publicly available in an open access repository with Mendeley Data at http://dx.doi.org/10.17632/x5m4zgfx5s.1 (DRAFT)

A preview can be found at https://data.mendeley.com/datasets/x5m4zgfx5s/draft?a=3aea7182-f382-441a-a0c4-93dd695eeb08

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## 14.3. Paper III. Feasibility and intervention study

# EXERCISE IN PATIENTS WITH ACETABULAR RETROVERSION AND EXCESSIVE ANTERIOR PELVIC TILT: A FEASIBILITY AND INTERVENTION STUDY

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**ABSTRACT**

**Purpose:** To investigate feasibility and change in patient-reported symptoms of a home-based exercise intervention in patients with acetabular retroversion and excessive anterior pelvic tilt, in comparison with a prior control period.

**Methods:** The sample size was n=36 patients (age 18–40 years) not eligible for surgery, with radiographic signs of acetabular retroversion on an anteroposterior radiograph in standing position, and excessive anterior pelvic tilt. Following an 8-week control period, patients participated in an 8-week (3 times/week) home-based exercise intervention. The intervention consisted of education, activity modification, stretching for posterior pelvic tilt mobility, muscle-strengthening for tilting the pelvis posteriorly, improving core stability, and pelvic movement control. Feasibility assessment included: dropout (≤10%), adherence (≥75% of sessions), exercise-related pain, and adverse events. Primary outcome was change in the Copenhagen Hip and Groin

Outcome Score (HAGOS) pain subscale. Secondary outcomes included change in the remaining HAGOS subscales, EQ-5D-3L questionnaire, and pelvic tilt measured by EOS scanning.

**Results:** Forty-two patients (93% female, mean ± SD, age 22.2 ± 4.2 years) were included. Three patients (7%) dropped out. Satisfactory adherence was demonstrated by 85%. Exercise-related pain and adverse events were acceptable. Between-period mean change score for HAGOS-PAIN subscale was 5.2 points (95% confidence interval [CI]: -0.3, 10.6) and -1.6 degree (95% CI: -3.9, 0.7) of anterior pelvic tilt. Patients who responded positively (≥minimal clinically important difference) (n = 10, 26%), had pre-exercise HAGOS-PAIN scores between 47.5 to 70 points.

**Conclusions:** Current exercise intervention was feasible. However, we found no clinically relevant changes in self-reported hip-related pain, function, quality of life, nor anterior pelvic tilt. Post hoc responder analysis revealed that patients with moderate pain at baseline might benefit from this exercise.

**Key Words:** *Femoroacetabular impingement, non-surgical treatment*

## INTRODUCTION

Acetabular retroversion is a variant of hip dysplasia (1) in which the cranial opening of the acetabulum is posterior, which may be explained by an externally rotated hemipelvis. As a result of acetabular retroversion, anterosuperior coverage of the femoral head is increased, enhancing the risk of pincer-type femoroacetabular impingement syndrome (FAIS) (1, 2). FAIS is associated with pain (3), reduced level of function (4), decreased health-related quality of life (5), and development of osteoarthritis (OA) of the hip (6, 7). Symptoms may be further exacerbated by anterior pelvic tilt as it functionally increases superior femoral head coverage (8, 9).

Currently, the standard treatment is non-surgical but a few patients may undergo periacetabular osteotomy (PAO) to reduce symptoms (10). PAO is associated with risks of complications and a subsequently long period of rehabilitation (11). Non-surgical interventions may provide low-risk and low-cost treatment options to reduce the symptoms of FAIS, and may hypothetically be a preferred option in patients with excessive anterior pelvis tilt. Exercise-based (12) physiotherapist-led interventions (13) in patients with various types of FAIS are supported with a low to moderate level of evidence for a short-term effect (14). However, the above evidence did not include FAIS in relation to acetabular retroversion nor pelvic tilt. Thus, no evidence exists on non-surgical treatment in reducing symptoms and excessive anterior pelvic tilt in patients with acetabular retroversion (15).

Therefore, the purpose was to investigate the feasibility of a progressive home-based exercise intervention targeting a normalization of excessive anterior pelvic tilt and the change in patient-reported symptoms in a prospective cohort of patients with acetabular retroversion and excessive anterior pelvic tilt. It was hypothesized that an 8-week progressive home-based exercise intervention would be feasible with regards to dropout, adherence to exercise, exercise-related pain, and adverse events, and would demonstrate clinically relevant improvements in patient-reported pain, function, and health-related quality of life, together with a normalization in pelvic anterior tilt, in comparison with a prior control period.

## METHODS

### Study design

The study was designed as a single-center, prospective intervention study using patients as their own controls. Following baseline examinations, an 8-week control period was followed by an 8-week home-based exercise period. Subsequently, the patients were encouraged to continue with the exercise program for an additional 16 weeks. The study was approved by the Regional Ethics Committee (ID: S-20160072) and registered with ClinicalTrials.gov (NCT03578562).

### Setting

Eligible patients with retroversion and referred to the outpatient clinic for PAO at Odense University Hospital (Denmark) but with symptoms not adequate for surgery were recruited from November 2018 to December 2019. All included patients gave written informed consent prior to testing.

**Participants**

Inclusion criteria were age 18 to 40 years old and acetabular retroversion (COS+ PWS) (1) from a frontal pelvic radiograph in a standard standing position. Exclusion criteria were pelvic-tilt-ratio greater than 0.5 (16) indicating posterior pelvic tilt; radiographic sign of hip osteoarthritis (<2 mm joint space); previous lumbar, pelvic or hip-related surgery; conditions not allowing exercise therapy; a body mass index (BMI) above 35; or not understanding spoken and/or written Danish language.

**Procedures**

Instructions for the exercise intervention, and distribution of the exercise program and training diary (see Appendix A, the complete exercise program and training diary) took place after the 8-week control period at Odense University Hospital. For the rationale for the exercise program, (see Appendix B, the rationale of the exercise program). In brief, the home-based exercise program was inspired by the international Warwick consensus statement on FAIS (17), previous exercise studies regarding various types of FAIS patients (18-21), and functional anatomy (22). The intervention consisted of education in the hip condition and activity modification, instructions in stretching exercises for posterior pelvic tilt mobility, strengthening muscles for tilting the pelvis posteriorly, improving body core stability, and pelvic movement control. The program (30–45 min) should be completed three times a week, with an optional extra session, allowing a rest day between each session. The progression (intensity, number of repetitions and/or level of difficulty of the exercises) increased every second week. However, some personalization of the exercise program (e.g., doing fewer repetitions or omitting an exercise that caused pain) was permitted, and should be noted in the training diary.

*Stopping guidance*

There was no *a priori* stopping guidance. However, patients were instructed to contact the study investigator (AFB) in case of questions regarding the exercise program or experience of exercise-related discomfort. If patients experienced exercise-related pain above 4 on a 0–10 numeric ranking scale (NRS) (23), where 0 is “no pain” and 10 is “pain as bad as it could be”, a booster session was added. Ultimately, if pain could not be reduced below 4 on the NRS, the training was stopped and the referring physician contacted.

**Outcome measures**

*Feasibility*

We prospectively defined good feasibility (24) of the progressive home-based exercise intervention as: A dropout rate ≤10%; adherence to the exercise program of ≥75% completion (18 out of 24 sessions); the ratio of training sessions increasing pre- to post-exercise-related pain (NRS >4) should not increase; no serious exercise-related adverse events; and no increase in usage of hip-related analgesics. Parameters regarding feasibility were recorded in the self-reported training diary.

*Time-points*

Outcome measures were collected at four time-points: T1) baseline, T2) start-up of exercise intervention 8 weeks from baseline, T3) end of exercise intervention after 8 weeks (primary endpoint), and T4) follow-up after 16-weeks (see Appendix C, 16-week follow-up results) (Figure 1).

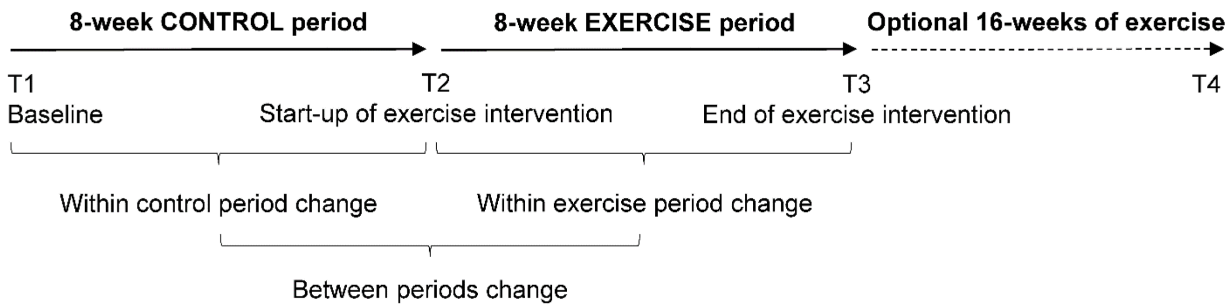


**FIGURE 1. Study design and time-points**

**Primary outcome measure**

The between-period change score in the pain subscale of the HAGOS questionnaire (HAGOS-PAIN) at T3 was registered *a priori* as the primary outcome measure. The HAGOS score ranges from 0 to 100 (0 equals "extreme hip and/or groin problems" and 100 equals "no hip and/or groin problems") (25). HAGOS has shown good reliability, validity, and responsiveness in young to middle-aged patients with longstanding hip and/or groin pain (25, 26).

**Secondary outcome measures**

*Patient-reported outcome measures*

Secondary outcome measures included between-period change scores of the remaining five HAGOS subscales (25) (Symptoms, Physical function in daily living, Physical function in Sport and Recreation, Participation in Physical Activities, and hip and/or groin-related Quality of Life), and the European Quality of Life questionnaire (EQ-5Dimensions-3Levels) (27) (index value set for Denmark) ranging from 0 to 1 (0 equals death and 1 equals full health). The clinimetric properties for EQ-5D-3L in patients having FAIS have not been reported, but EQ-5D-3L has been validated as a generic measure of general health (28).

*Objective outcome measure*

Change in pelvic tilt (sagittal inclination in degrees) was measured with low-dose radiation EOS scanning (EOS Imaging, Paris, France) in standardized standing position as the angle between a horizontal line and a line connecting the upper border of the symphysis with the sacral promontory (see Appendix D, EOS scan of pelvic inclination) (29). The bi-plane EOS radiographic imaging system has been found reliable (30) and valid (31) in assessing pelvic configurations. An experienced research radiographer (BM) and (AFB) found excellent inter-rater reliability (two-way random effects for absolute agreement) $ICC_{2.1}$ = 0.99 (95% CI: 0.98, 0.99) on the pelvic tilt measurements in 50 randomly selected EOS scans.

**Statistical analysis**

The sample size calculation was based upon two-sided paired means and the following statistical properties; alpha = 0.05 and power = 0.80. The minimal clinically important difference (MCID) for the HAGOS-PAIN subscale was estimated as 10 points (≈half a standard deviation) (32) and using a standard deviation of 20.6 points (25) resulted in a minimum of 36 patients to be included. Four additional patients were added to account for possible dropouts. Feasibility was analyzed according to potential relationship between time (the 8-week period) and (i) the ratio of patients exercising; (ii) the ratio of patients experiencing pre to post exercise-related pain (NRS >4); and (iii) the ratio of patients using analgesics, with Spearman's Rho.

Descriptive data and fitted regression residuals from the mixed-effects linear regression model were assessed for Gaussian distribution. A mixed-effects linear regression model, following the Intention To Treat (ITT) principle (33), adjusted for baseline values and accommodating missing data was used in the main analysis of change scores following intervention. A sensitivity analysis (per-protocol analysis) was conducted for patients demonstrating the *a priori* defined acceptable adherence to exercise (≥75%).

A *P*-value ≤0.05 was considered statistically significant, and estimates are presented with 95% confidence intervals. STATA/IC 16 software (StataCorp. LP, College Station, TX, USA) was used to perform statistical analyses.

*Post hoc analysis*

A responder analysis was carried out by investigating change in HAGOS-PAIN in the exercise period versus pre-exercise outcome values (HAGOS-PAIN, pelvic tilt, age and BMI). The Mann-Whitney U-test was used to test for potential differences in median HAGOS-PAIN change scores between the three intervals of pre-exercise HAGOS-PAIN scores (<1$^{st}$ quartile vs. IQR, and IQR vs. >3$^{rd}$ quartile).

**RESULTS**

Out of 42 included patients (39 women, 93%) (mean age of 22.2 ± 4.2 years, (Table 1), 39 (93%) completed the exercise intervention (Figure 2).

**TABLE 1. Descriptive statistics at baseline (n = 42)**

| | |
|---|---|
| **Patient characteristics** | |
| Sex, female, n (percent) | 39 (93) |
| Age, years | 22.2 ± 4.2 |
| BMI, kg/m$^2$ | 23.1 ± 4.6 |
| Height, m | 1.69 ± 0.1 |
| Weight, kg | 66.4 ± 13.3 |
| Affected hip, n (percent) | |
| None, | 1 (2) |
| Bilateral | 12 (29) |
| Left | 11 (26) |
| Right | 18 (43) |
| **PROM** | |
| HAGOS, subscales | |
| Pain | 59 ± 19.8 |
| Symptoms | 57.3 ± 17.5 |
| Physical function in daily living | 64.8 ± 22.5 |
| Physical function in Sport and Recreation Participation in | 56.7 ± 24.7 |
| Physical Activities | 47.9 ± 32.3 |
| Hip and/or groin-related Quality of Life | 40.8 ± 23.3 |
| EQ-5D-3L | 0.69 ± 0.2 |
| **Pelvic tilt** | |
| Pelvic tilt, degrees | 74.3 ± 8.4 |

*Values are mean* ± (standard deviation) *unless otherwise indicated.*
*Abbreviations: n (numbers), BMI (body mass index), PROM (patient-reported outcome measure), IQR (interquartile range), SD (standard deviation), HAGOS (The Copenhagen Hip and Groin Outcome Score), EQ-5D-3L (European Quality of Life-5 Dimensions-3 Levels index value)*

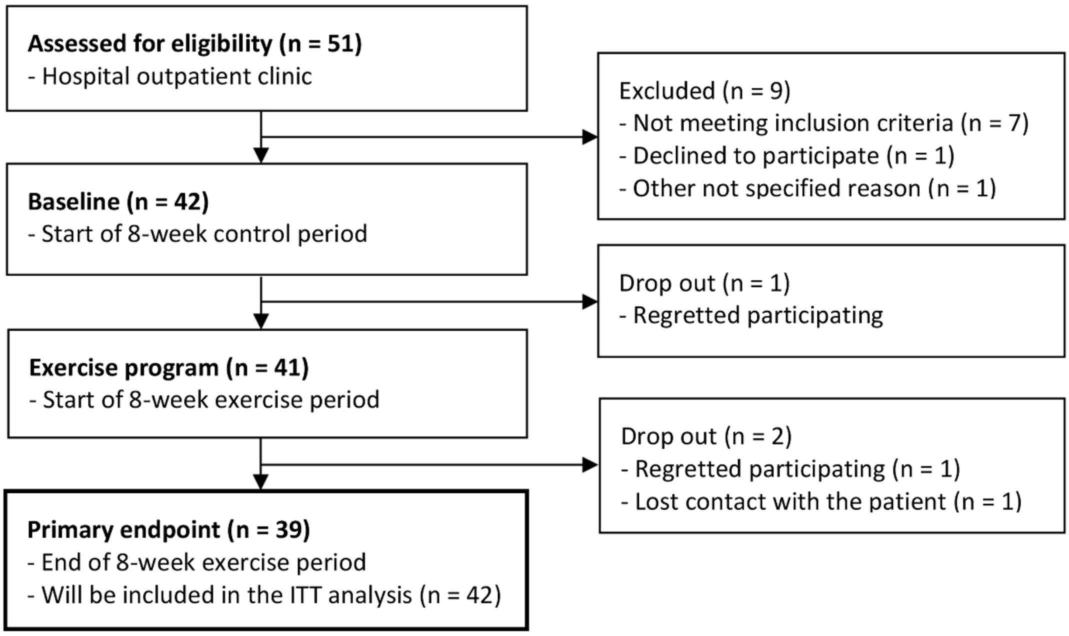


**FIGURE 2. Flow diagram of patients´ progress through the study**

**Feasibility**

Three patients (7%) dropped out of the study, one during the control period (regretting participation) and two during the intervention period (one patient regretting participation and one lost to follow-up).

Acceptable adherence to exercise was demonstrated by 33 (85%) patients. Reasons for non-adherence were: lack of motivation (n = 2), exercise-related hip pain (n = 2), side effect of prior surgery (not related to the hip) (n = 1), and no reason provided (n = 1). The ratio of patients exercising during the intervention period decreased from 100% in week 1 to 58% in week 8 ($r$ = -0.99, $P$ <0.01).

The percentage of training sessions that increased pre- to post exercise-related pain (NRS >4) decreased from 35% in week 1 to 18% in week 8 ($r$ = -0.79, $P$ = 0.02).

Exercise-related adverse events were most commonly reported as pain/discomfort (NRS >4) in the following exercises; strengthening the hip abductors (n = 13), strengthening the hip external rotators (n = 13), movement control in lying (“dying bug”) (n = 4), and three patients reported delayed onset of hip joint pain (2–3 hours after exercise).

The ratio of patients using analgesics decreased from 29% in week 1 to 12% in week 8 ($r$ = -0.90, $P$ <0.01).

## Exercise-related changes

*Primary outcome*

The intervention period demonstrated a non-significant improvement in mean HAGOS-PAIN of 5.2 points (95% CI: -0.3, 10.6) in comparison with the control period (*P* = 0.06) (Table 2).

**TABLE 2. Outcome change scores**

| | Control-period change | Exercise-period change | Between-periods change |
|---|---|---|---|
| **Primary outcome** | | | |
| **HAGOS *pain*–subscale** | | | |
| ITT | 0.4 (-2.7, 3.5) | **5.6 (2.4, 8.8) **** | 5.2 (-0.3, 10.6) |
| PP | 0.4 (-3.1, 3.9) | **5.3 (1.8, 8.8) **** | 4.9 (-1.2, 11.0) |
| **Secondary outcomes** | | | |
| **HAGOS, *subscales*:** | | | |
| *Symptoms* | | | |
| ITT | -1.0 (-4.5, 2.5) | **5.2 (1.7, 8.8) **** | **6.2 (0.2, 12.3) *** |
| PP | -2.0 (-6.0, 2.0) | **6.9 (2.9, 11.0) **** | **8.9 (1.9, 15.9) **** |
| *ADL* | | | |
| ITT | 3.6 (-0.5, 7.8) | 3.6 (-0.6, 7.9) | -0.02 (-7.3, 7.3) |
| PP | 3.3 (-1.2, 7.8) | 4.2 (-0.3, 8.7) | 0.9 (-6.9, 8.7) |
| *Sport/Rec* | | | |
| ITT | 2.0 (-2.0, 6.0) | **6.1 (2.0, 10.2) **** | 4.1 (-2.9, 11.1) |
| PP | <0.1 (-4.1, 4.1) | **6.7 (2.6, 10.9) **** | 6.7 (-0.4, 13.9) |
| *Physical Activities* | | | |
| ITT | 2.4 (-3.2, 8.1) | 0.7 (-5.1, 6.5) | -1.7 (-11.6, 8.2) |
| PP | -1.1 (-7.1, 4.8) | 3.8 (2.1, 9.7) | 4.9 (-5.3, 15.2) |
| *Quality of Life* | | | |
| ITT | 1.1 (-2.4, 4.6) | 2.8 (-0.8, 6.3) | 1.7 (-4.5, 7.8) |
| PP | -0.3 (-4.1, 3.5) | 3.5 (-0.3, 7.3) | 3.8 (-2.7, 10.3) |
| **EQ–5D–3L** | | | |
| ITT | 0.02 (-0.01, 0.06) | 0.01 (-0.03, 0.04) | -0.02 (-0.09, 0.05) |
| PP | 0.02 (-0.02, 0.06) | <0.01 (-0.04, 0.04) | -0.02 (-0.09, 0.05) |
| **Pelvic tilt, degrees** | | | |
| ITT | -0.4 (-1.7, 0.9) | **-2.0 (-3.3, -0.6) **** | -1.6 (-3.9, 0.7) |
| PP | -0.5 (-1.9, 1.0) | -1.4 (-2.9, 0.1) | -0.9 (-3.4, 1.6) |

*Mixed-effects linear regression model adjusted for baseline values. ITT (n = 42), PP (n = 33).*
*Data are expressed as mean (95% CI), *P <0.05, and **P <0.01*
*Abbreviations: ITT (intention to treat), PP (per protocol, ≥75% exercise adherence), HAGOS (The Copenhagen Hip and Groin Outcome Score), ADL= Physical function in daily living, Sport/Rec= Physical function in Sport and Recreation, Physical Activities= Participation in Physical Activities, Quality of Life= hip and/or groin-related Quality of Life, EQ-5D-3L (European Quality of Life-5 Dimensions-3 Levels index value.*

*Secondary outcomes*

Of the remaining HAGOS subscales, only Symptoms showed a significant mean between-periods improvement of 6.2 points (95% CI: 0.2, 12.3), (*P* = 0.04). Furthermore, no changes were observed for the EQ-5D-3L score nor the degree of pelvic tilt (Table 2).

*Per-protocol analysis*

The per-protocol analysis confirmed the ITT analysis, as no differences in change scores were identified (Table 2).

*Post hoc analysis*

A median HAGOS-PAIN change score of 7.5 points (IQR: 0, 12.5) in the pre-exercise IQR was significantly larger than the median scores of 2.5 points (IQR: 0, 5) (*P* = 0.04) and -1.25 points (IQR: -3.75, 3.75) (*P* = 0.01) for Q1 and Q3, respectively (Figure 3). Additionally, 10 out of 11 patients who responding positively (≥MCID) to the exercise intervention (n = 10, 26%), had a pre-exercise HAGOS-PAIN score within the IQR (between 47.5 to 70 points). A similar responder finding to the exercise intervention was not shown for pelvic tilt, age, or BMI.

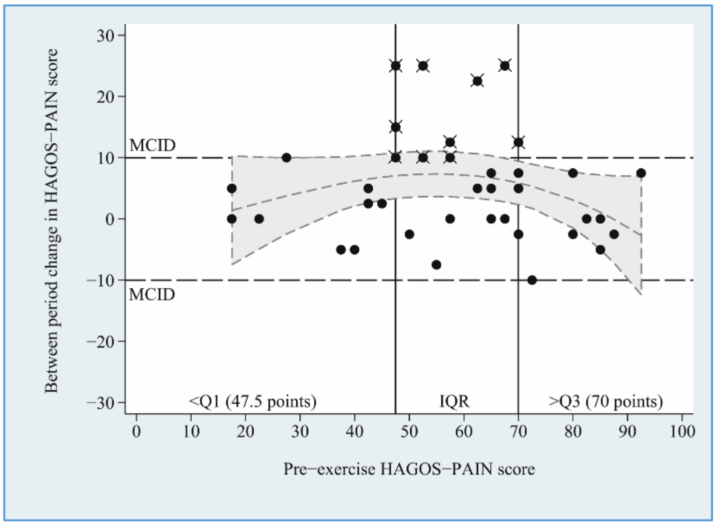


**FIGURE 3.** Change in HAGOS pain-subscale score post-exercise against pre-exercise HAGOS pain-subscale score. The horizontal dashed lines marks the *Minimal Clinical Important Difference* (MCID) of ± 10 points in the HAGOS-PAIN subscale. The vertical solid lines marks the first quartile (Q1) and the third quartile (Q3), and the in-between interquartile range (IQR). The grey area marks the 95% CI of the fitted regression line (grey center dashed line). Patients with positive or negative HAGOS-PAIN change scores (≥10 points) are defined as positive or negative responders, respectively. Ten of the eleven patients responding positively to exercise had pre-exercise HAGOS-PAIN score within the IQR (marked with an X). Some observations are superimposed, thus, there is a discrepancy between the actual number (n = 39) and observations seen in the figure.

**DISCUSSION**

In the present study, a targeted 8-week progressive home-based exercise intervention showed acceptable feasibility. However, results concerning adherence, exercise-related pain, and exercise-related adverse events were less conclusive. Overall, the study did not demonstrate statistically nor clinically significant changes in either the self-reported HAGOS-PAIN score (primary outcome) or the secondary outcome measures of function, quality of life, or pelvic positioning. However, post hoc analysis demonstrated that patients with moderate HAGOS-PAIN scores at baseline responded positively to the intervention opposed to patients with high or low levels of pain.

**Feasibility**

Only two patients dropped out during the 8-week intervention period, suggesting the practical execution of the home-based exercise program was feasible. Despite an overall acceptable adherence rate, the ratio of patients exercising decreased (from 100% to 58%) during the intervention period. The most common reasons for non-adherence were lack of motivation and pain.

The majority of intervention studies on patients with FAIS that include an exercise program specify a supervised program with a duration of 12 weeks (18, 34-37). Common to these studies is that they all reported improvement. Apart from one of those studies – a randomized controlled trial (RCT) (36) – the level of evidence ranges from medium (RCT pilots) (18, 34) to low (case series) (35, 37). This is emphasizing the potential necessity of supervision when conducting exercise programs (38). Nevertheless, in our study 21 patients continued to exercise unsupervised for the optional 16 weeks after the 8-week period. For those patients, a significant, but clinically non-relevant pain reduction (within-group median change of 7.5 (IQR: -2, 15), ($P = 0.01$), was observed (data not shown). However, only 3 patients continued exercising to the extent prescribed in the additional training period, which makes finding inconclusive (see Appendix C, 16-week follow-up results).

The ratio of training sessions increasing pre- to post exercise-related pain, and ratio of patients using analgesics decreased significantly over the 8-week period. However, this could be attrition biased, as the ratio of patients exercising was decreasing. Exercise-related adverse events were most commonly reported in hip muscle-strengthening exercises. Despite potential discomfort, muscle-strengthening is considered essential for patients with FAIS in establishing joint stability and decreasing labral load (39).

**FAIS and non-surgical interventions**

Until now, no studies on non-surgical interventions have been conducted on a group of homogeneous patients with acetabular retroversion (i.e., pincer-type FAIS). The body of evidence on non-surgical intervention for patients with FAIS is mainly based on studies in which either the majority of participants are patients with cam-type FAIS (34, 36, 40, 41) or the type/distribution of FAIS is not reported (18-21, 42, 43). However, pincer-type FAIS is associated with the shape and/or orientation of the acetabulum, controlling the pelvis and thus the orientation of the acetabulum seems especially important (44).

Most non-surgical intervention studies on patients with FAIS have applied protocols including trunk muscle-strengthening exercises, but with no explicit definition of pelvic control (19, 21, 34, 35, 40, 41, 45). However, one RCT (36) demonstrated within-group improved function and reduced pain following a 12-week training intervention targeting pelvic, hip and abdominal musculature, in combination with encouragement of posteriorly tilting the pelvis. However, evidence is sparse and future trials are needed to determine whether exercises targeting an excessive anterior pelvic tilt reduction are superior to general trunk muscle strength training in reducing symptoms in patients with FAIS, and whether the training effect differs in pincer versus cam FAIS.

**Responder analysis**

Post hoc analysis revealed that patients with moderate pre-exercise HAGOS-PAIN mid-range scores (47.5–70 points) responded positively to exercise. It is likely that the sub-group of patients with severe pain experienced exercise-related pain limiting the potential benefit (flooring effect), or the condition is so severe that exercise is not the right treatment. Patients with low levels of pain already demonstrate high levels of physical activity and relatively low levels of symptoms, resulting in a potential ceiling effect.

**Pelvic inclination**

Females accounted for the largest proportion of patients (93%), which is more than previously reported (66% females (46) and 66% males (10)). Pelvic inclination has been reported to be equal between the sexes, with an inclination of approximately 60°–65° in both (47). However, the patients in our study had a mean anterior pelvic tilt (inclination) of 74° ±8.4° at baseline, which is 9°–14° more than the above-mentioned normal range. However, it has not been reported whether increased anterior pelvic tilt is a characteristic in patients with acetabular retroversion. The current results are limited by measuring static pelvic tilt only and thus, we cannot infer if the patient´s occurrence of impingement in dynamic movements has changed. Thus, we find it of clinical interest to further investigate (e.g., by three-dimensional motion capture analysis) if targeting exercises can reduce excessive anterior pelvic tilt during dynamic activities in daily living, and whether this would improve patient symptoms.

**Strength and limitations to the study**

The strengths of this feasibility and intervention study include: A study protocol was publicly available prior to patient enrollment ensuring methodological transparency; the exercise intervention is reported according to the TIDieR (48) and CERT (49) checklists for reporting interventions; and the content of the targeted exercise intervention is consistent with recommendations from a recent literature review (50) of non-operative management of individuals with non-arthritic hip pain, and international consensus recommendations for hip-related pain and FAIS (12, 17).

The intervention part of the study is limited by no randomization to parallel groups; consequently, no clear causality can be drawn from the current study design. The design, however, provided a control period prior to the training period, from which no change in patient-reported outcomes or pelvic tilt occurred. Furthermore, the study was limited by a short intervention period and unsupervised training. However, we chose this approach because a pilot study we conducted prior to this intervention indicated that the preferred training was home-based because of difficulties in meeting for supervised sessions. Additionally, patients with acetabular retroversion are referred from a large geographic area; consequently a pragmatic approach of home-based intervention was chosen. To allow additional guidance for patients, we provided the option of a booster session; however, only 11 patients (28%) took advantage of this. Thus, retrospectively we speculate that optional booster sessions are not as effective in maintaining motivation for exercising as supervised training might have been.

## CONCLUSION

This 8-week home-based exercise intervention was feasible in patients with acetabular retroversion and excessive anterior pelvic tilt. However, improvements on supervision and duration of the intervention should be considered. No clinically relevant improvement in self-reported hip-related pain, function, or quality of life were observed, nor was any significant reduction in excessive anterior pelvic tilt. However, post hoc responder analysis revealed that patients with moderate pain might benefit from this type of exercise program.

## ACKNOWLEDGMENTS

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## CONFLICT OF INTEREST

All authors declare that there is no conflict of interest. The results of the present study do not constitute endorsement by the American College of Sports Medicine. All authors declare that the findings of the present study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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## DATA SHARING

Data are available in a public, open access repository with Mendeley Data,

http://dx.doi.org/10.17632/h4bmjrs7gc.2

## APPENDICES

Appendix A, the complete exercise program and training diary

Appendix B, the rationale of the exercise program

Appendix C, 16-week follow-up results

Appendix D, EOS scan of pelvic inclination

## Appendix A, the complete exercise program and training diary

# 8-week home-based exercise program for patients with acetabular retroversion and excessive anterior pelvic tilt

**Background**
Anterior pelvic tilt is known to increase the risk of impingement of the hip joint and is potentially associated with hip-related pain.

The aim of the exercise program is to reduce the level of hip-related pain and the degree of anterior pelvic tilt.

**Principals of the exercise program**
It is an 8-week home-based unsupervised exercise program consisting of stretching exercises for posterior pelvic tilt mobility, muscle strengthening exercises for tilting the pelvis posteriorly, and exercises for improving body core stability as well as pelvic movement control. Each exercise session initiates with stretching exercises, followed by muscle strengthening exercises and ending with specific exercises for tilting the pelvis posteriorly.

The frequency of the program is planned for three times a week, with an optional extra session. Duration of the daily program the first two weeks (module 1) is planned at approximately 30 minutes. For the remaining six weeks (module 2), the exercise program will gradually increase in length as the number of repetitions increases. In case of adverse events or difficulties related to he exercise program (e.g., pain, discomfort, exercise performance) the study investigator can be contacted (contact information is found on the last page).

Following the eight weeks of exercising, it is assessed in consultation with you whether the training should continue for an additional 16 weeks. Experience of hip-related pain exceeding 4 on a 0-10 scale (0 = *no pain,* 10 = *worst possible pain)* before, during, and after exercise must be noted in the training diary.

## GET THE MOST OUT OF THE EXERCISE PROGRAM

**During the exercise period, please:**

- Do not begin new physically strenuous activities, as it may cause extra stress on your hip
- Do not place your hip in a maximum flexed position, as it increases the risk of impingement.
- Do not sit with your legs crossed, as it increases the risk of impingement.

Keep an even weight distribution on both legs when standing. Reduce anterior pelvic tilt by tighten the abdominal and gluteal muscles when you stand and walk. Bending your lower back in situations when you are flexing the hips will tilt your pelvis posteriorly, and reduce the risk of impingement.

## OVERVIEW OF THE PROGRESSION OF THE EXERCISE PROGRAM

| **Module I – Exercises (first two weeks)** | **Week 1-2** |
|---|---|
| #1 Stretching the anterior hip | 2 sets of 30 sec. |
| #2 Stretching the low back | 2 sets of 30 sec. |
| #3 Stretching the anterior thigh | 2 sets of 30 sec. |
| #4 Strengthening the hip abductors | 2 sets of 10 reps. |
| #5 Strengthening the hip external rotators (Clamshell) | 2 sets of 10 reps. |
| #6 Spinal mobility (Cat & Camel) | 1 set of 10 reps. |
| #7 Core stability (Bird Dog) | 3 sets of 10 reps. |
| #8 Movement control in lying (Pelvic tilt) | 2 sets of 10 reps. |
| #9 Core stability (Static plank) | 2 sets of 15 sec. |
| #10 Strengthening the abdominal muscles (Crunch) | 2 sets of 10 reps. |
| #11 Strengthening the abdominal muscles (Oblique crunch) | 2 sets of 10 reps. |
| #12 Movement control in standing (Supported pelvic tilt) | 1 set of 10 reps. |
| #13 Movement control in standing (Unsupported pelvic tilt) | 1 set of 10 reps. |

| **Module II – Exercises (from week 3 to 8)** | **Week 3-4** | **Week 5-6** | **Week 7-8** |
|---|---|---|---|
| #1 Stretching the anterior hip | 2 sets of 30 sec. | 2 sets of 30 sec. | 2 sets of 30 sec. |
| #2 Stretching the low back | 2 sets of 30 sec. | 2 sets of 30 sec. | 2 sets of 30 sec. |
| #3 Stretching the anterior thigh | 2 sets of 30 sec. | 2 sets of 30 sec. | 2 sets of 30 sec. |
| #4 Strengthening the hip abductors | 2 sets of 10 reps. | 3 sets of 10 reps. | 4 sets of 10 reps. |
| #5 Strengthening the hip external rotators (Clamshell) | 2 sets of 10 reps. | 3 sets of 10 reps. | 4 sets of 10 reps. |
| #6 Spinal mobility (Cat & Camel) | 1 set of 10 reps. | 1 set of 10 reps. | 1 set of 10 reps. |
| #7 Movement control in lying (Dying bug) | 2 sets of 10 reps. | 3 sets of 10 reps. | 4 sets of 10 reps. |
| #8 Movement control in lying (Single leg pelvic tilt) | 2 sets of 10 reps. | 3 sets of 10 reps. | 4 sets of 10 reps. |
| #9 Strengthening the hip extensors | 2 sets of 10 reps. | 3 sets of 10 reps. | 4 sets of 10 reps. |
| #10 Core stability (Dynamic plank) | 2 sets of 10 reps. | 3 sets of 10 reps. | 4 sets of 10 reps. |
| #11 Movement control in standing (Sup. pelvic tilt) | 1 set of 10 reps. | 1 set of 10 reps. | 1 set of 10 reps. |
| #12 Movement control in standing (Unsup. pelvic tilt) | 1 set of 10 reps. | 1 set of 10 reps. | 1 set of 10 reps. |

**TRAINING DIARY**

**Write the date you begin the exercise program:** ____________________

**Which hip-s do you experience symptoms from** (one X)**:**

- Both hips equally _____ Both but primarily the left _____ Both but primarily the right _____
- Only the left hip _____
- Only the right hip _____

**How often did you use analgesics because of hip-related pain before beginning the exercise program?** (one X)

- Never _____
- Monthly _____
- Weekly _____
- Daily _____

**Type(s) of analgesics:** ____________________________________________________________________

| | **Hip-related pain** | | | **Comments** |
|---|---|---|---|---|
| **Week 1** | Before exercise (0-10) | During exercise (0-10) | After exercise (0-10) | Please write comments to exercises that cause discomfort |
| Monday | | | | |
| Tuesday | | | | |
| Wednesday | | | | |
| Thursday | | | | |
| Friday | | | | |
| Saturday | | | | |
| Sunday | | | | |

**Did you use analgesics because of hip-related pain in this week:** **yes**___ **no**____

**If yes, please write how often and which type:**

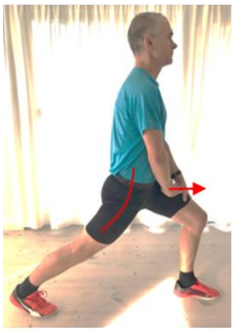
**TRAINING DIARY**

| | Hip-related pain | | | Comments |
|---|---|---|---|---|
| **Week 2** | Before exercise (0-10) | During exercise (0-10) | After exercise (0-10) | Please write comments to exercises that cause discomfort |
| Monday | | | | |
| Tuesday | | | | |
| Wednesday | | | | |
| Thursday | | | | |
| Friday | | | | |
| Saturday | | | | |
| Sunday | | | | |

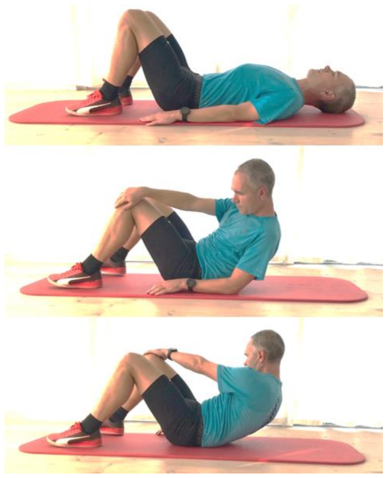
**Did you use analgesics because of hip-related pain in this week:** **yes___** **no____**

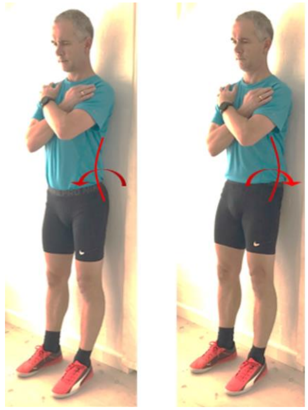
**If yes, please write how often and which type:**

______________________________________________________________________________

| EXERCISES - WEEK 1-2 | |
|---|---|
| **#1 Stretching the anterior hip (Fencer stretch)**<br>Start by standing in a fencer's lunge-like position, with the back leg in the same plane as the front leg and the foot pointing forward. Maintain a posterior pelvic tilt (flat lumbar spine) and do not let the back arch, then shift the body weight onto the anterior leg until a stretching sensation is felt in the anterior hip region of the back leg (i.e., the red line on the picture).<br><br>**2 x 30 sec. alternately with both legs** |  |
| **#2 Stretching the low back**<br>From the standing position, the upper body is bent forward toward one leg (e.g., right) and tension may be felt on the (left) side of the low back. Keep the position for five seconds and then shift to the other leg while staying in the forward bent position. Continue shifting from leg to leg for a total of 30 seconds in intervals of 5 seconds.<br><br>**2 x 30 sec. with a break in an upright position between** |  |
| **#3 Stretching the anterior thigh**<br>Standing with the hip extended and knee flexed and grasping the ankle. Maintain a posterior pelvic tilt (flat lumbar spine) without letting the back arch or the side bend during the stretch.<br><br>**2 x 30 sec. alternately with both legs** |  |
| **#4 Strengthening the hip abductors**<br>In the side-lying position, raise the upper leg with the toes pointing straight forward to approximately 75 % of full range-of-motion to avoid discomfort.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**2 sets of 10 repetitions alternately with both legs**<br>**(make fewer repetitions if the full number is not possible)** |  |

| | |
|---|---|
| **#5 Strengthening the hip external rotators (Clamshell)**<br>In the side-lying position, externally rotate the upper leg with the feet kept together by moving the upper knee towards the ceiling. Use the resistance band to adjust the load or perform the exercise without the resistance band.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**2 sets of 10 repetitions alternately with both legs**<br>**(make fewer repetitions if the full number is not possible)** |   |
| **#6 Spinal mobility (Cat & Camel)**<br>In the quadruped position, alternately bend and stretch the spine to end-range positions in a slow rhythm.<br><br>**1 set of 10 repetitions** |   |
| **#7 Core stability (Bird Dog)**<br>In the quadruped position, maintain a neutral position in the spine, alternately raise one arm and the diagonal leg, until the arm and leg are at a horizontal level with the spine.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**3 sets of 10 repetitions alternately diagonally**<br>**(make fewer repetitions if the full number is not possible)** |  |
| **#8 Movement control in lying (Pelvic tilt)**<br>In the supine position with the hips and knee bend, the pelvis is tilted posteriorly while simultaneously lifting it from the floor.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**2 sets of 10 repetitions**<br>**(make fewer repetitions if the full number is not possible)** |   |

| | |
|---|---|
| **#9 Core stability (Static plank)**<br>In the plank position on the knees and elbows, maintain a posterior pelvic tilt (flat lumbar spine).<br><br>**2 sets of 15 sec.**<br>**(shorten the time if the position cannot be sustained)** |  |
| **#10 Strengthening the abdominal muscles (Crunch)**<br>In the supine position with the hips and knees bent, the lower back is pressed towards the floor and the upper body is raised with the hands reaching for the knees.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**2 sets of 10 repetitions**<br>**(make fewer repetitions if the full number is not possible)** |  |
| **#11 Strengthening the abdominal muscles (Oblique crunch)**<br>In the supine position with the hips and knee bent, the low back is pressed towards the floor and. the upper body is then lifted and rotated, with one hand (e.g. right) reaching for the opposite knee (left). Alternate from side to side.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**2 sets of 10 repetitions**<br>**(make fewer repetitions if the full number is not possible)** |  |

| | |
|---|---|
| **#12 Movement control in standing (Supported pelvic tilt)**<br>In the standing position with the shoulder blades and pelvis in contact with the wall (knees slightly bent), the pelvis is tilted posteriorly until the lower back touches the wall. Alternatively, the hands can be placed on the pelvis to guide the movement.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**1 set of 10 repetitions** |  |
| **#13 Movement control in standing (Unsupported pelvic tilt)**<br>The exercise is performed similarly as exercise #12 but without wall support.<br><br>In daily life, this pelvic movement can be used to improve standing posture.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**1 set of 10 repetitions** |  |

**TRAINING DIARY**

| | Hip-related pain | | | Comments |
|---|---|---|---|---|
| **Week 3** | Before exercise (0-10) | During exercise (0-10) | After exercise (0-10) | Please write comments to exercises that cause discomfort |
| Monday | | | | |
| Tuesday | | | | |
| Wednesday | | | | |
| Thursday | | | | |
| Friday | | | | |
| Saturday | | | | |
| Sunday | | | | |

**Did you use analgesics because of hip-related pain in this week:** **yes___ no____**

**If yes, please write how often and which type:**

______________________________________________________________________________________

**TRAINING DIARY**

| | Hip-related pain | | | Comments |
|---|---|---|---|---|
| **Week 4** | Before exercise (0-10) | During exercise (0-10) | After exercise (0-10) | Please write comments to exercises that cause discomfort |
| Monday | | | | |
| Tuesday | | | | |
| Wednesday | | | | |
| Thursday | | | | |
| Friday | | | | |
| Saturday | | | | |
| Sunday | | | | |

**Did you use analgesics because of hip-related pain in this week:** **yes___ no____**

**If yes, please write how often and which type:**

________________________________________________________________________________________

## EXERCISES - WEEK3-4

**#1 Stretching the anterior hip (Fencer stretch)**
Start by standing in a fencer's lunge-like position, with the back leg in the same plane as the front leg and the foot pointing forward. Maintain a posterior pelvic tilt (flat lumbar spine) and do not let the back arch, then shift the body weight onto the anterior leg until a stretching sensation is felt in the anterior hip region of the back leg (i.e., the red line on the picture).

**2 x 30 sec. alternately with both legs**

**#2 Stretching the low back**
From the standing position, the upper body is bent forward toward one leg (e.g., right) and tension may be felt on the (left) side of the low back. Keep the position for five seconds and then shift to the other leg while staying in the forward bent position. Continue shifting from leg to leg for a total of 30 seconds in intervals of 5 seconds.

**2 x 30 sec. with a break in an upright position between**

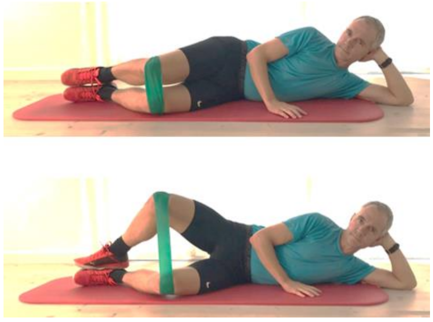
**#3 Stretching the anterior thigh**
Standing with the hip extended and knee flexed and grasping the ankle. Maintain a posterior pelvic tilt (flat lumbar spine) without letting the back arch or the side bend during the stretch.

**2 x 30 sec. alternately with both legs**

**#4 Strengthening the hip abductors**
In the side-lying position, raise the upper leg with the toes pointing straight forward to approximately 75 % of full range-of-motion to avoid discomfort.

Speed: 1 sec. to reach end-position and 1 sec. to return

**2 sets of 10 repetitions alternately with both legs**
**(make fewer repetitions if the full number is not possible)**

| | |
|---|---|
| **#5 Strengthening the hip external rotators (Clamshell)**<br>In the side-lying position, externally rotate the upper leg with the feet kept together by moving the upper knee towards the ceiling. Use the resistance band to adjust the load or perform the exercise without the resistance band.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**2 sets of 10 repetitions alternately with both legs**<br>**(make fewer repetitions if the full number is not possible)** |  |
| **#6 Spinal mobility (Cat & Camel)**<br>In the quadruped position, alternately bend and stretch the spine to end-range positions in a slow rhythm.<br><br>**1 set of 10 repetitions** |  |
| **#7 Movement control in lying (Dying bug)**<br>Start in the supine position with bent hips and knees, hands on the knees, and the low back pressed down to the floor. Diagonal arm and leg are stretched to a level just above the floor. The low back must be in contact with the floor at all times.<br><br>In case the exercise is too strenuous, the heel can slide touching the floor when stretched.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**2 sets of 10 repetitions alternately diagonally**<br>**(make fewer repetitions if the full number is not possible)** |  |

| | |
|---|---|
| **#8 Movement control in lying (Single leg pelvic tilt)**<br>In the supine position with one hip and knee bent and the other leg straight, the pelvis is lifted simultaneously from the floor without arching the lumbar spine.<br><br>In case the exercise is too strenuous, the leg can be placed on a chair to be supported instead of being straight.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**2 sets of 10 repetitions**<br>**(make fewer repetitions if the full number is not possible)** |  |
| **#9 Strengthening the hip extensors**<br>In a quadruped position supported on elbows, one hip is extended until the leg is in a straight line with the body.<br><br>If impingement symptoms are experienced from the weight-bearing hip, the exercise should not be performed.<br>Tighten the abdominal muscles to avoid lumbar lordosis.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**2 sets of 10 repetitions**<br>**(make fewer repetitions if the full number is not possible)** |  |

| | |
|---|---|
| **#10 Core stability (Dynamic plank)**<br>In the plank position on the knees and elbows, maintain a posterior pelvic tilt (flat lumbar spine). One arm reaches to the side while keeping the core stable, and the movement is repeated alternating with the other arm.<br><br>In case the exercise is too strenuous, perform the static plank exercise from week 1-2 instead (number 9).<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**2 sets of 10 repetitions**<br>**(make fewer repetitions if the full number is not possible)** | <br> |
| **#12 Movement control in standing (Supported pelvic tilt)**<br>In the standing position with the shoulder blades and pelvis in contact with the wall (knees slightly bent), the pelvis is tilted posteriorly until the lower back touches the wall. Alternatively, the hands can be placed on the pelvis to guide the movement.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**1 set of 10 repetitions** |  |
| **#12 Movement control in standing (Unsupported pelvic tilt)**<br>The exercise is performed similarly as exercise #12 but without wall support.<br><br>In daily life, this pelvic movement can be used to correct standing posture.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**1 set of 10 repetitions** |  |

**TRAINING DIARY**

| | Hip-related pain | | | Comments |
|---|---|---|---|---|
| **Week 5** | Before exercise (0-10) | During exercise (0-10) | After exercise (0-10) | Please write comments to exercises that cause discomfort |
| Monday | | | | |
| Tuesday | | | | |
| Wednesday | | | | |
| Thursday | | | | |
| Friday | | | | |
| Saturday | | | | |
| Sunday | | | | |

**Did you use analgesics because of hip-related pain in this week:** **yes___ no____**

**If yes, please write how often and which type:**

______________________________________________________________________________

**TRAINING DIARY**

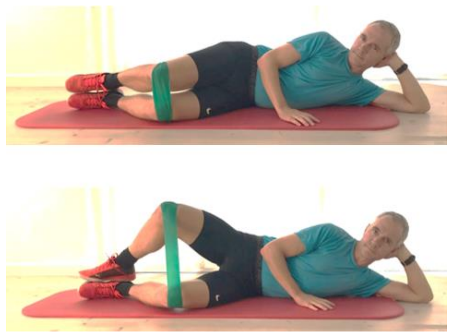
| | Hip-related pain | | | Comments |
|---|---|---|---|---|
| **Week 6** | Before exercise (0-10) | During exercise (0-10) | After exercise (0-10) | Please write comments to exercises that cause discomfort |
| Monday | | | | |
| Tuesday | | | | |
| Wednesday | | | | |
| Thursday | | | | |
| Friday | | | | |
| Saturday | | | | |
| Sunday | | | | |

**Did you use analgesics because of hip-related pain in this week:** **yes___ no____**

**If yes, please write how often and which type:**

______________________________________________________________________________

| **EXERCISES - WEEK 5-6** | |
|---|---|
| **#1 Stretching the anterior hip (Fencer stretch)**<br>Start by standing in a fencer's lunge-like position, with the back leg in the same plane as the front leg and the foot pointing forward. Maintain a posterior pelvic tilt (flat lumbar spine) and do not let the back arch, then shift the body weight onto the anterior leg until a stretching sensation is felt in the anterior hip region of the back leg (i.e., the red line on the picture).<br><br>**2 x 30 sec. alternately with both legs** |  |
| **#2 Stretching the low back**<br>From the standing position, the upper body is bent forward toward one leg (e.g., right) and tension may be felt on the (left) side of the low back. Keep the position for five seconds and then shift to the other leg while staying in the forward bent position. Continue shifting from leg to leg for a total of 30 seconds in intervals of 5 seconds.<br><br>**2 x 30 sec. with a break in an upright position between** |  |
| **#3 Stretching the anterior thigh**<br>Standing with the hip extended and knee flexed and grasping the ankle. Maintain a posterior pelvic tilt (flat lumbar spine) without letting the back arch or the side bend during the stretch.<br><br>**2 x 30 sec. alternately with both legs** |  |
| **#4 Strengthening the hip abductors**<br>In the side-lying position, raise the upper leg with the toes pointing straight forward to approximately 75 % of full range-of-motion to avoid discomfort.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**3 sets of 10 repetitions alternately with both legs**<br>**(make fewer repetitions if the full number is not possible)** |  |

<table>
<tr>
<td>#5 Strengthening the hip external rotators (Clamshell)<br>In the side-lying position, externally rotate the upper leg with the feet kept together by moving the upper knee towards the ceiling. Use the resistance band to adjust the load or perform the exercise without the resistance band.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>3 sets of 10 repetitions alternately with both legs<br>(make fewer repetitions if the full number is not possible)</td>
<td></td>
</tr>
<tr>
<td>#6 Spinal mobility (Cat & Camel)<br>In the quadruped position, alternately bend and stretch the spine to end-range positions in a slow rhythm.<br><br>1 set of 10 repetitions</td>
<td></td>
</tr>
<tr>
<td>#7 Movement control in lying (Dying bug)<br>Start in the supine position with bent hips and knees, hands on the knees, and the low back pressed down to the floor. Diagonal arm and leg are stretched to a level just above the floor. The low back must be in contact with the floor at all times.<br><br>In case the exercise is too strenuous, the heel can slide touching the floor when stretched.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>3 sets of 10 repetitions alternately diagonally<br>(make fewer repetitions if the full number is not possible)</td>
<td></td>
</tr>
</table>

<table>
<tr>
<td>#8 Movement control in lying (Single leg pelvic tilt)<br>In the supine position with one hip and knee bent and the other leg straight, the pelvis is lifted simultaneously from the floor without arching the lumbar spine.<br><br>In case the exercise is too strenuous, the leg can be placed on a chair to be supported instead of being straight.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>3 sets of 10 repetitions<br>(make fewer repetitions if the full number is not possible)</td>
<td><br></td>
</tr>
<tr>
<td>#9 Strengthening the hip extensors<br>In a quadruped position supported on elbows, one hip is extended until the leg is in a straight line with the body.<br><br>If impingement symptoms are experienced from the weight-bearing hip, the exercise should not be performed.<br>Tighten the abdominal muscles to avoid lumbar lordosis.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>3 sets of 10 repetitions<br>(make fewer repetitions if the full number is not possible)</td>
<td><br></td>
</tr>
</table>

**#10 Core stability (Dynamic plank)**
In the plank position on the knees and elbows, maintain a posterior pelvic tilt (flat lumbar spine). One arm reaches to the side while keeping the core stable, and the movement is repeated alternating with the other arm.

In case the exercise is too strenuous, perform the static plank exercise from week 1-2 instead (number 9).

Speed: 1 sec. to reach end-position and 1 sec. to return

**3 sets of 10 repetitions**
**(make fewer repetitions if the full number is not possible)**

**#11 Movement control in standing (Supported pelvic tilt)**
In the standing position with the shoulder blades and pelvis in contact with the wall (knees slightly bent), the pelvis is tilted posteriorly until the lower back touches the wall. Alternatively, the hands can be placed on the pelvis to guide the movement.

Speed: 1 sec. to reach end-position and 1 sec. to return

**1 set of 10 repetitions**

**#12 Movement control in standing (Unsupported pelvic tilt)**
The exercise is performed similarly as exercise #12 but without wall support.

In daily life, this pelvic movement can be used to correct standing posture.

Speed: 1 sec. to reach end-position and 1 sec. to return

**1 set of 10 repetitions**

**TRAINING DIARY**

| | Hip-related pain | | | Comments |
|---|---|---|---|---|
| **Week 7** | Before exercise (0-10) | During exercise (0-10) | After exercise (0-10) | Please write comments to exercises that cause discomfort |
| Monday | | | | |
| Tuesday | | | | |
| Wednesday | | | | |
| Thursday | | | | |
| Friday | | | | |
| Saturday | | | | |
| Sunday | | | | |

**Did you use analgesics because of hip-related pain in this week:** **yes___ no____**

**If yes, please write how often and which type:**

_____________________________________________________________________________________

**TRAINING DIARY**

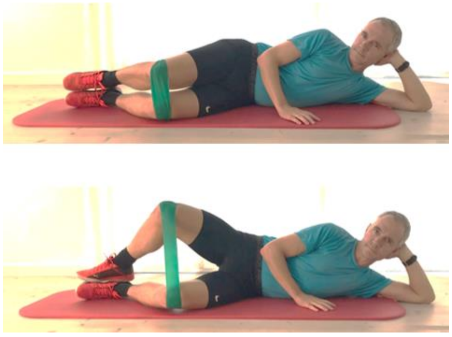
| | Hip-related pain | | | Comments |
|---|---|---|---|---|
| **Week 8** | Before exercise (0-10) | During exercise (0-10) | After exercise (0-10) | Please write comments to exercises that cause discomfort |
| Monday | | | | |
| Tuesday | | | | |
| Wednesday | | | | |
| Thursday | | | | |
| Friday | | | | |
| Saturday | | | | |
| Sunday | | | | |

**Did you use analgesics because of hip-related pain in this week:** **yes___ no____**

**If yes, please write how often and which type:**

______________________________________________________________________________

| EXERCISES - WEEK 7-8 | |
|---|---|
| **#1 Stretching the anterior hip (Fencer stretch)**<br>Start by standing in a fencer's lunge-like position, with the back leg in the same plane as the front leg and the foot pointing forward. Maintain a posterior pelvic tilt (flat lumbar spine) and do not let the back arch, then shift the body weight onto the anterior leg until a stretching sensation is felt in the anterior hip region of the back leg (i.e., the red line on the picture).<br><br>**2 x 30 sec. alternately with both legs** |  |
| **#2 Stretching the low back**<br>From the standing position, the upper body is bent forward toward one leg (e.g., right) and tension may be felt on the (left) side of the low back. Keep the position for five seconds and then shift to the other leg while staying in the forward bent position. Continue shifting from leg to leg for a total of 30 seconds in intervals of 5 seconds.<br><br>**2 x 30 sec. with a break in an upright position between** |  |
| **#3 Stretching the anterior thigh**<br>Standing with the hip extended and knee flexed and grasping the ankle. Maintain a posterior pelvic tilt (flat lumbar spine) without letting the back arch or the side bend during the stretch.<br><br>**2 x 30 sec. alternately with both legs** |  |
| **#4 Strengthening the hip abductors**<br>In the side-lying position, raise the upper leg with the toes pointing straight forward to approximately 75 % of full range-of-motion to avoid discomfort.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**4 sets of 10 repetitions alternately with both legs**<br>**(make fewer repetitions if the full number is not possible)** |  |

| | |
|---|---|
| **#5 Strengthening the hip external rotators (Clamshell)**<br>In the side-lying position, externally rotate the upper leg with the feet kept together by moving the upper knee towards the ceiling. Use the resistance band to adjust the load or perform the exercise without the resistance band.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**4 sets of 10 repetitions alternately with both legs**<br>**(make fewer repetitions if the full number is not possible)** |  |
| **#6 Spinal mobility (Cat & Camel)**<br>In the quadruped position, alternately bend and stretch the spine to end-range positions in a slow rhythm.<br><br>**1 set of 10 repetitions** |  |
| **#7 Movement control in lying (Dying bug)**<br>Start in the supine position with bent hips and knees, hands on the knees, and the low back pressed down to the floor. Diagonal arm and leg are stretched to a level just above the floor. The low back must be in contact with the floor at all times.<br><br>In case the exercise is too strenuous, the heel can slide touching the floor when stretched.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**4 sets of 10 repetitions alternately diagonally**<br>**(make fewer repetitions if the full number is not possible)** |  |

| | |
|---|---|
| **#8 Movement control in lying (Single leg pelvic tilt)**<br>In the supine position with one hip and knee bent and the other leg straight, the pelvis is lifted simultaneously from the floor without arching the lumbar spine.<br><br>In case the exercise is too strenuous, the leg can be placed on a chair to be supported instead of being straight.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**4 sets of 10 repetitions**<br>**(make fewer repetitions if the full number is not possible)** |  |
| **#9 Strengthening the hip extensors**<br>In a quadruped position supported on elbows, one hip is extended until the leg is in a straight line with the body.<br><br>If impingement symptoms are experienced from the weight-bearing hip, the exercise should not be performed.<br>Tighten the abdominal muscles to avoid lumbar lordosis.<br><br>Speed: 1 sec. to reach end-position and 1 sec. to return<br><br>**4 sets of 10 repetitions**<br>**(make fewer repetitions if the full number is not possible)** |  |

**#10 Core stability (Dynamic plank)**
In the plank position on the knees and elbows, maintain a posterior pelvic tilt (flat lumbar spine). One arm reaches to the side while keeping the core stable, and the movement is repeated alternating with the other arm.

In case the exercise is too strenuous, perform the static plank exercise from week 1-2 instead (number 9).

Speed: 1 sec. to reach end-position and 1 sec. to return

**4 sets of 10 repetitions**
**(make fewer repetitions if the full number is not possible)**

**#11 Movement control in standing (Supported pelvic tilt)**
In the standing position with the shoulder blades and pelvis in contact with the wall (knees slightly bent), the pelvis is tilted posteriorly until the lower back touches the wall. Alternatively, the hands can be placed on the pelvis to guide the movement.

Speed: 1 sec. to reach end-position and 1 sec. to return

**1 set of 10 repetitions**

**#12 Movement control in standing (Unsupported pelvic tilt)**
The exercise is performed similarly as exercise #12 but without wall support.

In daily life, this pelvic movement can be used to correct standing posture.

Speed: 1 sec. to reach end-position and 1 sec. to return

**1 set of 10 repetitions**

**Please write any personal comments you might have on the exercise program:**

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

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______________________________________________________________________________

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______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

**In case of questions to the exercise program, please contact the study investigator:**

Name: x

Phone: x

Email: x

# Appendix B, the rationale of the exercise program

## THE TILT-FAIS EXERCISE PROGRAM

The working title of the exercise program was TILT-FAIS, referring to the intervention targeting reduction of excessive anterior pelvic tilt (TILT), and femoroacetabular impingement syndrome (FAIS).

### The rationale of the exercise program

Pelvic and hip joint movements are interrelated, with posterior pelvic rotation throughout the entire hip flexion, accounting for approximately 20%–25% of overall hip flexion (1). Additionally, a 10 degree increase in anterior or posterior pelvic tilt results in a 10 degree respective loss or gain in hip flexion (2). The exercise program was inspired by the international Warwick consensus statement on FAIS(3), previous studies on exercise interventions regarding various types of FAIS patients (4-7), and functional anatomy (8). If the pelvis is free to move, it can be tilted posteriorly, as a result of a force couple whereby the abdominal muscles rotate the pelvis upward anteriorly together with the gluteus maximus muscle, and hamstring muscles rotate the pelvis downward posteriorly (8, p. 462). The exercise program consisted of stretching for posterior pelvic tilt mobility (anterior hip, low back, anterior thigh), strengthening hip abductor and extensor muscles for tilting the pelvis posteriorly, and exercises focusing on improving body core stability (strengthening the abdominal muscles) as well as pelvic movement control. Each exercise session began with stretching exercises, continued through muscle strength training and ended with specific posture-improving exercises on tilting the pelvis posteriorly (i.e., movement control in standing exercises).

### Instructions

The exercise program was designed for home use without supervision. Therefore, thorough oral, written, and practical information and instructions were emphasized during the consultation at the hospital's motion laboratory (time-point T2) just prior to initiation of the 8-week exercise period. The patients were instructed to add the exercise program to their normal daily routine (i.e., a continuation of the control period) in the exercise intervention period. Therefore, during the intervention period it was acceptable to continue participating in physical activities that had been conducted in the control period, as long as the exercise program was prioritized. The study investigator informed all patients individually of their hip condition (acetabular retroversion), the relationship between excessive anterior pelvic tilt and risk of FAIS, and how to modify activity to avoid FAIS, rehearsed with them the training exercises of the intervention and how to fill out the training diary, and offered suggestions on maintaining motivation for exercising (eg, exercising with others or in a gym). Finally, the patients received a hard copy of the exercise program, and the training diary. The patients received a TheraBand (TheraBand, OH, USA) exercise band that was optional to use in adjusting the resistance in the Clamshell exercise. The study investigator had nine years of experience with clinical physiotherapy practice including planning, instructing, and evaluating exercise therapy.

**Intensity and progression**

The exercise program was intended to be completed three to four times a week, with a rest day in between. In the first two weeks (module I), the duration of the exercise program was planned for approximately 30 minutes. For the remaining six weeks (module II), the exercise program gradually increased in time spent, as the number of repetitions increased (up to 45 min.).

The exercise program increased in progression every second week. In the first two weeks (Module I) the specific exercises regarding muscle-strengthening exercises and movement control in lying exercises were less demanding. In the remaining six weeks (Module II) the muscle-strengthening exercises and movement control exercises were increasingly more demanding. The exercises were the same throughout Module II. There were three progressions regarding the muscle-strengthening exercises and movement control in lying exercises (week 3–4, 2 sets of 10 repetitions; week 5–6, 3 sets of 10 repetitions; week 7–8; 4 sets of 10 repetitions). The stretching exercises and movement control in standing exercises remained unchanged throughout the 8-week exercise period.

**Exercise techniques**

The stretching exercises were performed dynamically for 30 seconds, with controlled end-range movements without bouncing (9), and painful hard end stretches (10). The movement speed was 1 second to reach end-position and 1 second to return. The patients were instructed to do fewer repetitions if the full number of repetitions could not be performed, and note this in the training diary. Dynamic and static core stability and muscle control exercises targeting posterior pelvic tilt stabilization were a primary focus areas in all exercises (11).

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## Appendix C, 16-week follow-up results

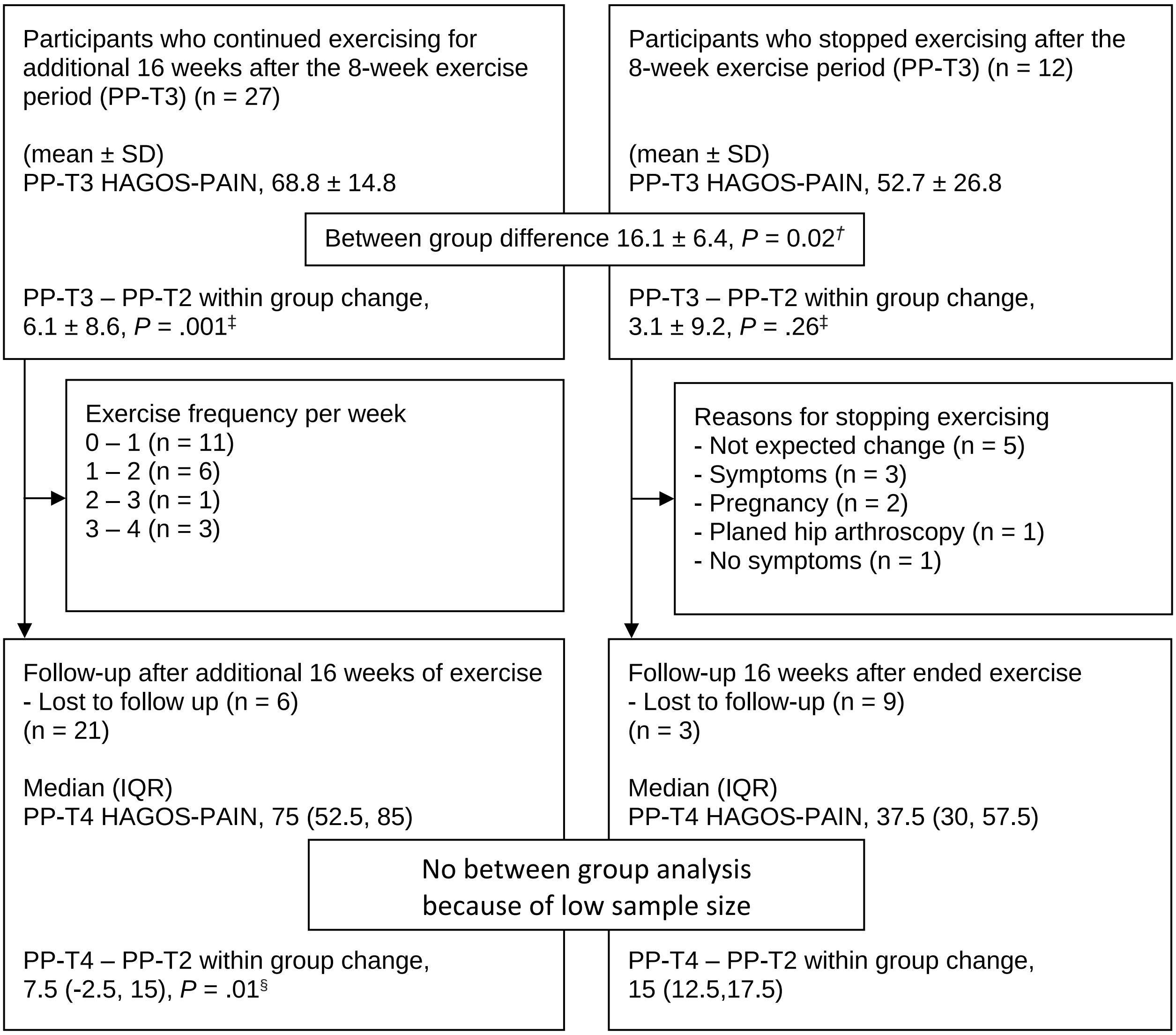


**Figure – Overview of patient´s progress after 8-week exercising**.
Abbreviations: PP: per protocol dividing of the patients who continue to exercise and those who stop, T2: *´start-up of exercise intervention´ 8 weeks from baseline*, T3: *´end of exercise intervention´* after 8 weeks (primary endpoint), T4: follow-up after 16-weeks, IQR: interquartile range.
[†] Independent t test, [‡] Paired t test, [§] Wilcoxon Signed-Rank Test

Twenty-seven (69%) of the patients continued exercising for additionally 16 weeks after the 8-week period. Patients who continued exercising reported less pain (16.1 ± 6.4 HAGOS-PAIN points, *P* = .02) after the prior 8-week training, in comparison to patients that stopped. Additionally, patients that continued exercising had a significant pain reduction of 6.1 ± 8.6 HAGOS-PAIN points, *P* = .001, by exercising over the 8-week period, in comparison to a smaller and non-significant pain reduction of 3.1 HAGOS-PAIN points ± 9.2, *P* = .26 in the patients that stopped.

After a total of 24 weeks (8 weeks + additional 16 weeks), a significant, but not clinically relevant mean pain reduction (within group median change of 7.5 (IQR: -2.5, 15), *P* = 0.01), was observed in patients (n = 21) continuing exercising. This is comparable with the overall mean change of 5.2 HAGOS-PAIN points (95% CI: -0.3, 10.6), (*P* = 0.06), suggesting that a continuation of exercising do not add change in hip-related pain. However, only 3 patients continued exercising to the extent as prescribed in the additional training period, which makes it inconclusive whether exercising beyond 8 weeks will change hip-related pain in patients with acetabular retroversion.

# Appendix D, EOS scan of pelvic inclination


**Figure** – Pelvic inclination depicted (86 degrees) with lateral EOS® scanning in standardized standing position as the angle between a horizontal line and a line connecting the upper border of the symphysis with the sacral promontory.