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Role of the Extraosseus Blood Supply in Osteoarthritic Femoral Heads?

Ralf Schoeniger MD, Norman Espinosa MD, Rafael J. Sierra MD, Michael Leunig MD, Reinhold Ganz MD

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Abstract Blood perfusion to the femoral head might be endangered during the surgical approach or the preparation of the femoral head or both in hip resurfacing arthroplasty. The contribution of the intramedullary blood supply to the femoral head in osteoarthritis is questionable. Therefore, the contribution of the extraosseous blood supply to osteoarthritic femoral heads was measured intraoperatively to question if there is measurable blood flow between the epiphysis and metaphysis in osteoarthritic hips in case of extraosseus vessel damage. At defined points during surgery we acquired the epiphyseal and metaphyseal femoral head perfusion by high-energy laser Doppler flowmetry. Complete femoral neck osteotomy sparing the retinacular vessels to simulate intraosseous blood disruption showed unchanged epiphyseal blood flow compared to initial measurement after capsulotomy. The pulsatile signal disappeared after transection of the retinacular vessels. Based on these acute measurements, we conclude intramedullary blood vessels to the femoral head do not provide measurable blood supply to the epiphysis once the medial femoral circumflex artery or the retinacular vessels have been damaged. We recommend the use of a safe surgical approach for hip resurfacing and careful implantation of the femoral component to respect blood supply to the femoral head and neck region in hip resurfacing arthroplasty.

Introduction

Hip resurfacing arthroplasty (HRA) has become increasingly popular for treating arthritis in the young, active patient. Concerns exist, however, about damage to the medial femoral circumflex artery (MFCA). This can occur during the surgical approach if performed through the posterior approach or damage to the superior retinacular vessels (RV), which can occur at the time of femoral head preparation regardless of the approach used [1, 4, 5, 18, 26, 28].

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Each author certifies that his or her institution has approved or waived approval for the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.
This study was performed at the Department of Orthopaedic Surgery, University of Berne and Department of Orthopaedic Surgery, Balgrist, University of Zurich, Switzerland.

R. Schoeniger (✉)
Department of Orthopaedic Surgery, Spital Bern-Ziegler, Morillonstrasse 75-91, 3001 Berne, Switzerland
e-mail: ralf.schoeniger@swissonline.ch

N. Espinosa
Department of Orthopaedic Surgery, University of Zurich, Balgrist, Zurich, Switzerland

R. J. Sierra
Department of Orthopaedic Surgery, Mayo Clinic, Rochester, MN, USA

M. Leunig
Hip Service, Clinic Schulthess, Zurich, Switzerland

M. Leunig
University of Berne, Berne, Switzerland

R. Ganz
Department of Orthopaedic Surgery, University of Berne, Berne, Switzerland

Favorable midterm results of HRA using posterior approach have been reported, however it might be associated with a risk of femoral neck fracture ranging between 0% to 12% [6, 7, 10, 12, 14, 21, 25, 27]. In failed HRA, osteonecrosis was found in the majority (92%–100%) of the retrieved femoral heads [21, 25, 27].

The importance of intraosseous blood flow to supply an osteoarthritic femoral head is under debate. Trueta et al. and others suggested the blood supply to the femoral head originates from epiphyseal and metaphyseal vessels that cross the physis after closure [9, 16, 17, 32–34]. In contrast, Sevitt and Thompson proposed a separate epiphyseal and metaphyseal circulation in the adult hip [24]. In an animal study, Whiteside et al. demonstrated the existence of epimetaphyseal anastomoses. These could make osteoarthritic hips less vulnerable to osteonecrosis after damage to the retinacular vessels when compared to nonarthritic hips [35].

We investigated the contribution of the extraosseus blood supply to the osteoarthritic hip with High-Energy Laser Doppler Flowmetry (LDF). Based on the work of Sevitt and Thompson [24], we hypothesized there is insufficient blood flow between the epiphysis and metaphysis in osteoarthritic hips in case of extraosseus vessel damage (MFCA), suggesting the MFCA is the major blood supply to the epiphysis in the osteoarthritic femoral head.

Materials and Methods

We recruited ten nonconsecutive patients with symptomatic hypertrophic osteoarthritis of the hip scheduled to undergo total hip arthroplasty (THA). We excluded patients with prior ipsilateral hip surgery, diabetes, malignant tumors and a history of peripheral vascular disease. None of the patients were on platelets aggregation inhibitors, heparin or Coumadin. There were seven female and three male patients with a mean age of 66 years (range, 45–85 years) and a mean BMI of 28.7 (range, 23.4–33.2). Four patients were on antihypertensive medication. An a priori power analysis was conducted to estimate the number of specimens needed. In this analysis, we assumed first that the intraindividual differences are normally distributed. Second, a two-tailed test with a significance level of 5% would be performed. Third, the mean of the differences is for the factor f (effect size) higher than the standard deviation of the difference. A factor f of 1.3 will lead to a power of $> 95\%$. Based on previous data a factor f of 1.4 was estimated. Therefore a sample size of 10 patients would be needed. Informed consent was obtained from all patients. The study was approved by the local ethics committee.

All patients received normotensive general anesthesia. To ensure proper signal amplitudes, the level of anesthesia was held constant during the period of data acquisition. The patient was positioned in the lateral decubitus position and a transgluteal approach performed. After exposure of the anterolateral capsule, a Z-shaped capsulotomy to preserve the retinacular vessels (RV) from the MFCA was carried out (Fig. 1). LDF was used to measure the blood perfusion [3, 23, 30]. The probe was inserted anteriorly into the bone through a 3.5-mm drill hole directly into the metaphysis and epiphysis (Fig. 1). The probe was placed into the anterosuperior quadrant of the femoral head to measure the epiphyseal blood flow (EBF) and into the femoral neck to assess the metaphyseal blood flow (MBF). The same probe placement was used by several authors in the past [4, 28]. The position of the probe was guided and verified using an image intensifier. The probe was removed between each measurement to allow unhindered surgical dissection. During surgery, LDF monitoring was conducted according to a specific protocol (Table 1).

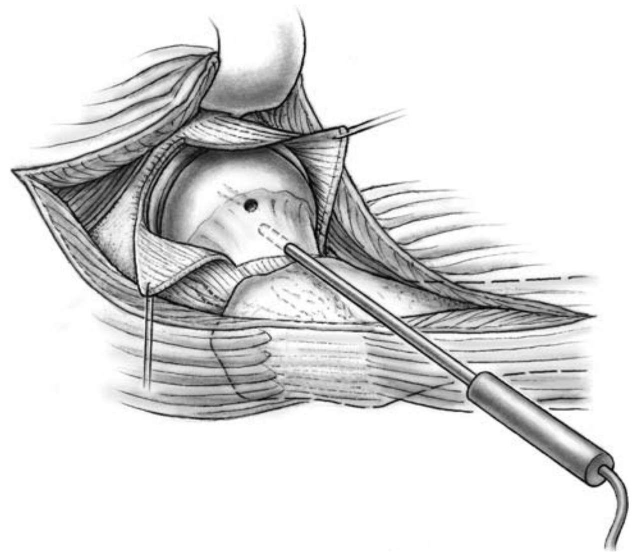

Fig. 1 Anterolateral view of a right hip after a transgluteal approach and z-shaped capsulotomy. The epiphyseal and metaphyseal drill hole are shown in the anterior femoral neck with the laser probe in the metaphysis.

Table 1. Blood flow measurement protocol

Measurement	Procedure
1	EBF/MBF after capsulotomy
2	EBF/MBF before compression of RV
3	EBF/MBF at compression of RV
4	EBF/MBF after compression of RV
5	EBF/MBF after femoral neck osteotomy
6	EBF after femoral neck osteotomy and dissection of RV

A high-power laser Doppler source (20 mW, emitting wavelength 780 nm) was used in combination with a conventional laser Doppler flowmeter (DRT4; Moor Instruments, Axminster, UK). The combination of a higher energy and an increased distance between emitting and receiving fibers increased the volume of bone sampled, which resulted in a more accurate signal-to-noise ratio. The reflected light was amplified by an analog processor (mV) and digitally processed. Blood flow was measured in FLUX units, which reflects the product of concentration and velocity of erythrocytes within the volume beneath the probe. FLUX was described in arbitrary units (AU), which are defined by calibration against a standard reference of polystyrene microspheres as provided by the manufacturer.

Initial blood flow measurements were recorded after calibration of the LDF (Measurement 1). Compression of the retinacular and terminal branches of the deep branch of the MFCA was simulated by placing an elastic rubber loop around the femoral neck for 30 seconds by the same surgeon in all cases (Fig. 2). Accurate vascular compression was verified by observing a nonpulsatile signal with the LDF. Further LDF data were acquired before, during, and after release of the rubber band (measurement 2–4). All measurements were accomplished with the probe placed at the metaphysis and epiphysis. After measurement four the rubber band was removed. Next, the terminal branches of the MFCA were dissected within their retinacular flap [20]. The femoral neck osteotomy was performed from anteroinferior to posterosuperior while ensuring preservation of the RV. This osteotomy simulates the disruption of the intraosseus blood supply to the femoral head. EBF and MBF were recorded in measurement five with preservation of the RV. For the final measurement six, the RV were ligated. After recording all six measurements, the femoral head fragment was removed and a THA performed.

The signals were continuously recorded in real time and stored for later analysis on a DRT4 Windows computer software program Version 1.1 (Moor Instruments, Axminster, UK). The time constant was set at 0.1 second and the display rate was set at 20 seconds to enable the visualization of pulsatile signals (eg, signal amplitudes synchronous to the heart rate as checked by electrocardiogram). Mean values and standard deviation of the waves were calculated during a period of at least 10 seconds after the signal had stabilized.

The signal amplitudes were compared in each individual before and after performing each measurement using a Friedman and Wilcoxon signed rank test (Prism v4, GraphPad Software, La Jolla, USA).

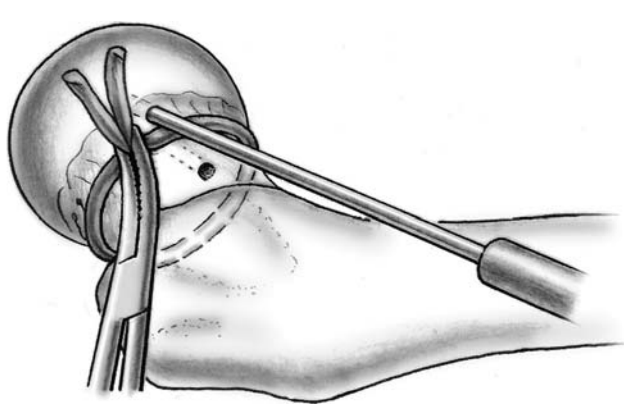

Fig. 2 The drawing shows an anterolateral view of a right hip with the rubber band in place for compression of the retinacular vessels.

Results

In all 10 patients, a pulsatile heart beat synchronic signal was recorded with the probe in the anterosuperior quadrant of the femoral head (EBF) and the femoral neck (MBF). The mean epiphyseal and metaphyseal blood flow (measurement 1) were similar ($p = 0.8457$): 141.4 AU (range 75.2 AU to 417.2 AU) and 142.6 AU (range 32.4 AU to 392.8 AU), respectively (Fig. 3). The mean EBF decreased ($p < 0.0001$) from 82.3 AU to 29.6 AU with loss of the pulsatile signal pattern and returned to 77.8 AU after pressure relief (measurement 2–4) (Fig. 4A). The mean MBF decreased ($p = 0.0001$) from 90.9 AU to 54.5 AU during compression but without loss of the pulsatile signal and returned to 101.1 AU after release of the RV (measurement 2–4) (Fig. 4B).

The mean EBF was similar ($p = 0.9118$) before (measurement 1) and after femoral neck osteotomy with preservation of the RV (measurement 5): 141.4 AU and 194.1 AU, respectively (Fig. 5). After transection of the

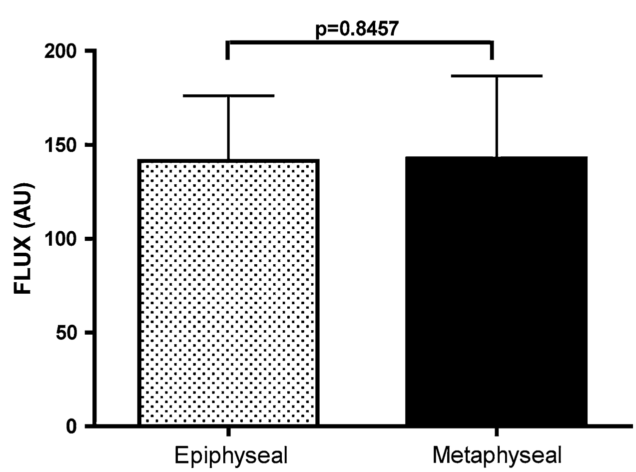

Fig. 3 The graph shows the mean values (and standard error of the mean) of the epiphyseal and metaphyseal blood flow signal after capsulotomy. No difference ($p = 0.8457$) was measured between the epiphyseal and metaphyseal blood flow.

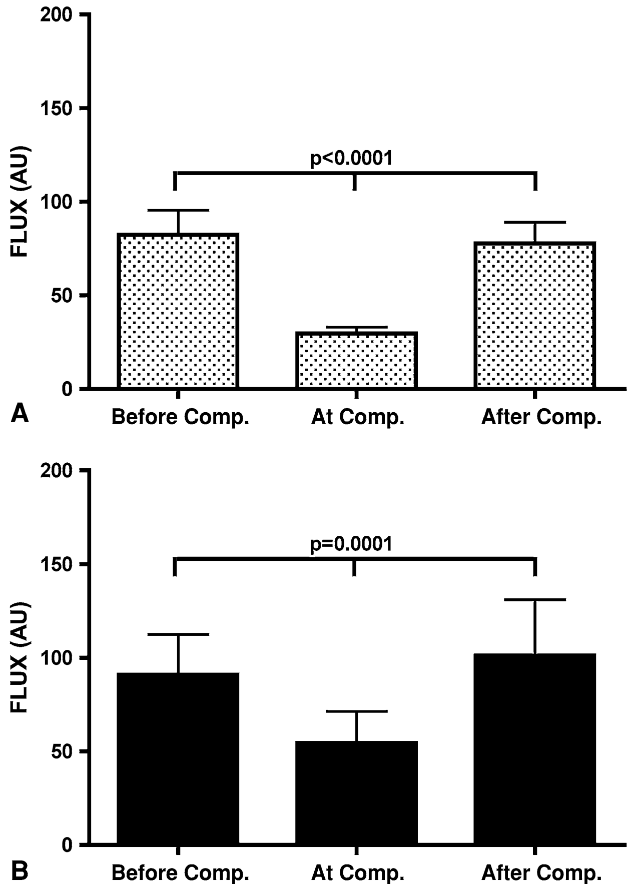

Fig. 4A–B The mean values (and standard error of the mean) of the epiphyseal blood flow and metaphyseal blood flow signal are shown before compression of the retinacular vessels, at compression, and after compression. The epiphyseal blood flow (**A**) decreased ($p < 0.0001$) after compression of the RV and there is a loss of the pulsatile signal. Compression of the RV decreased ($p = 0.0001$) the metaphyseal blood flow (**B**) without loss of the pulsatile signal.

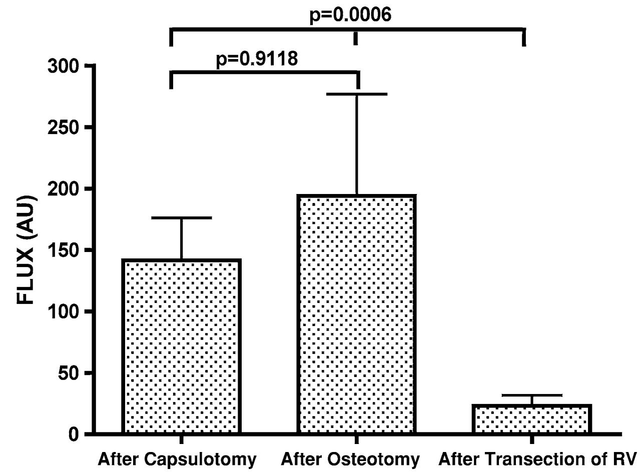

Fig. 5 The graph shows the mean values (and standard error of the mean) of the epiphyseal blood flow signal after capsulotomy, after complete femoral neck osteotomy, and after additional transection of the retinacular vessels. The epiphyseal blood flow after capsulotomy demonstrates no difference to a complete femoral neck osteotomy ($p = 0.9118$). The additional transection of the RV decreased ($p = 0.0006$) the blood flow with loss of the pulsatile signal.

RV (measurement 6) the mean EBF decreased ($p = 0.0006$) to 22.9 AU with a nonpulsatile signal pattern (Fig. 5). The mean MBF before femoral neck osteotomy was 61 AU (measurement 1) and decreased ($p = 0.9015$) to 55.2 AU after osteotomy (measurement 5). MBF after osteotomy was measured in seven of the 10 patients. In the remaining three patients the neck osteotomy extended into the drill hole used for the measurement. A new drill hole could have led to a change in data acquisition.

Discussion

Blood perfusion to the femoral head can be endangered during either the surgical approach to or the preparation of the femoral head or both in hip resurfacing arthroplasty. The intramedullary blood supply to the femoral head in osteoarthritis is believed to be variable. The purpose of this study was to investigate if an intraosseous blood flow between the epiphysis and metaphysis exists to maintain blood supply to the osteoarthritic femoral head in case of damage to the MFCA.

We note several limitations. First, LDF cannot measure absolute blood flow and cannot be used to identify a critical level for developing avascular necrosis. However, it can identify substantial changes of blood flow in the femoral head in any individual [19, 29, 31]. Second, we were unable to obtain a control group without osteoarthritic changes to make a direct comparison. A control group would consist of patients without an arthritic hip who require a femoral neck osteotomy. However, such patients were rare and therefore, we are unable to conclusively state whether osteophytic changes around the femoral head affect the epiphyseal blood flow. A comparison of our results with the results from Nötzli et al. [22] in 32 non-arthritic hips shows a mean EBF of 141.4 AU compared to the mean EBF of 69 AU. These results suggest the osteophytes do not compromise the epiphyseal blood flow. Third, the use of general anesthesia or regional anesthesia may lead to differences in blood flow measurements. All patients in the study received general anesthesia, which did not deviate from previous LDF studies of the hip [1, 5, 22]. Only in the study by Nötzli et al. [22] patients received either spinal or general anesthesia without differences in the amount of blood flow.

Our in vivo study suggests osteoarthritic changes to the femoral head do not lead to the establishment of measurable intramedullary perfusion between the epiphysis and metaphysis. After compression of the RV, the EBF was decreased and the pulsatile signal pattern disappeared completely (Fig. 4A). However, we observed no difference in signal when femoral neck osteotomy with preservation of the superior RV was performed to simulate intraosseous blood disruption (Fig. 5). Additional transection of the RV leads to a decrease with a nonpulsatile signal pattern. These findings strongly support, at least in this in vivo setting, that there is little intraosseous blood flow to the epiphysis of the osteoarthritic femoral head in case of extraosseous vessel (MFCA) damage. This finding is in agreement with Sevitt and Thompson [24] who, based on anatomic dissections, proposed separate epiphyseal and metaphyseal blood circulation to the femoral head. In their studies, they concluded that the superior RV were the major blood supply to the femoral head in 57 cadaveric specimens. They also reported vessels from the femoral neck never supplied the medial three-fourths of the head.

Our data contrast with the conclusions of earlier studies from Judet et al. [17] and Trueta and Harrison [33]. They suggest the epiphyseal blood supply was generated from vessels crossing from the metaphysis to the epiphysis of the femoral head in the normal hip. In arthritic hips Hulth et al. [16] and Arnoldi et al. [2] also studied the intramedullary blood supply and suggested it was more important than in nonarthritic hips. These investigators did not identify any functional importance of these intramedullary vessels to the viability of the osteoarthritic femoral head. Furthermore, due to epimetaphyseal anastomoses, Whiteside et al. [35] suggested stripping of the retinaculum in osteoarthritic hips did not totally devascularize the femoral head compared with nonarthritic hips; because they were uncertain the remaining anastomoses would provide adequate blood supply they suggested damage to the RV should be avoided [35].

Recent studies suggest a posterior approach for HRA and preparation of the femoral head with subsequent placement of the implant may impair blood flow to the femoral head through damage to the superior RV [4, 5, 28]. Beaule et al. [4, 5] measured the blood flow in the anterosuperior quadrant of the femoral head with LDF and showed reduced blood flow after performing a posterior approach, reaming of the femoral head and femoral neck notching (representing an insult to the medial femoral circumflex artery rather than a mechanical damage). Steffen et al. [28] found reduced oxygen concentration measured with silver electrodes in the femoral head after posterior approach and implantation of the femoral component.

In contrast, using an anterolateral, transgluteal or trochanteric flip approach, blood flow of the femoral head is not diminished compared with the posterior approach [1, 18, 26]. Khan et al. [18] measured the cefuroxime concentration in bone samples of the femoral head during HRA implantation. They found substantial reduced concentration in the posterolateral approach compared to a transgluteal approach. Amarasekera et al. [1] investigated the blood flow in the femoral head/neck junction with LDF in the posterior and trochanteric flip approach. A reduction of 40% was measured in the posterior approach and 11% in the trochanteric flip approach. Furthermore, Steffen et al. [26] reported that femoral oxygenation is markedly reduced when using the posterior approach compared to the anterolateral and trochanteric flip approach. If damage to these vessels occurs during surgery, the medullary blood flow may not be sufficient to allow continued perfusion of the femoral head as demonstrated by the present study. However, none of these experimental data were associated with a high failure rate in the midterm results of HRA implantation with the use of a posterior approach [8, 14, 25]. This might be explained by sufficient persisting blood flow or flow through anastomoses between the MFCA and the inferior gluteal artery [11, 13, 15, 17] that can prevent osteonecrosis of the femoral head.

In summary, our in vivo study provides further evidence that intramedullary blood vessels to the femoral head provide little blood flow to the epiphysis once the MFCA or the RV have been damaged. Based on our findings and the results of other authors [1, 26], we recommend the use of a surgical approach for hip resurfacing that respects the critical blood supply to the femoral head and neck region. The careful implantation of the femoral component to avoid notching or the use of an implant that prevents notching of the femoral neck and damage to the retinacular vessels may also be important for the long-term durability of hip resurfacing arthroplasty.

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